Technical Report CERC-93-9
June 1993

US Army Corps
of Engineers
Waterways Experiment
Station

Annual Data Summary for 1991 CERC Field Research Facility

Volume I: Main Text and Appendixes A and B

by Michael W. Leffler, Clifford F. Baron,
Brian L. Scarborough, Kent R. Hathaway
Coastal Engineering Research Center

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Prepared for Headquarters, U.S. Army Corps of Engineers

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Final report

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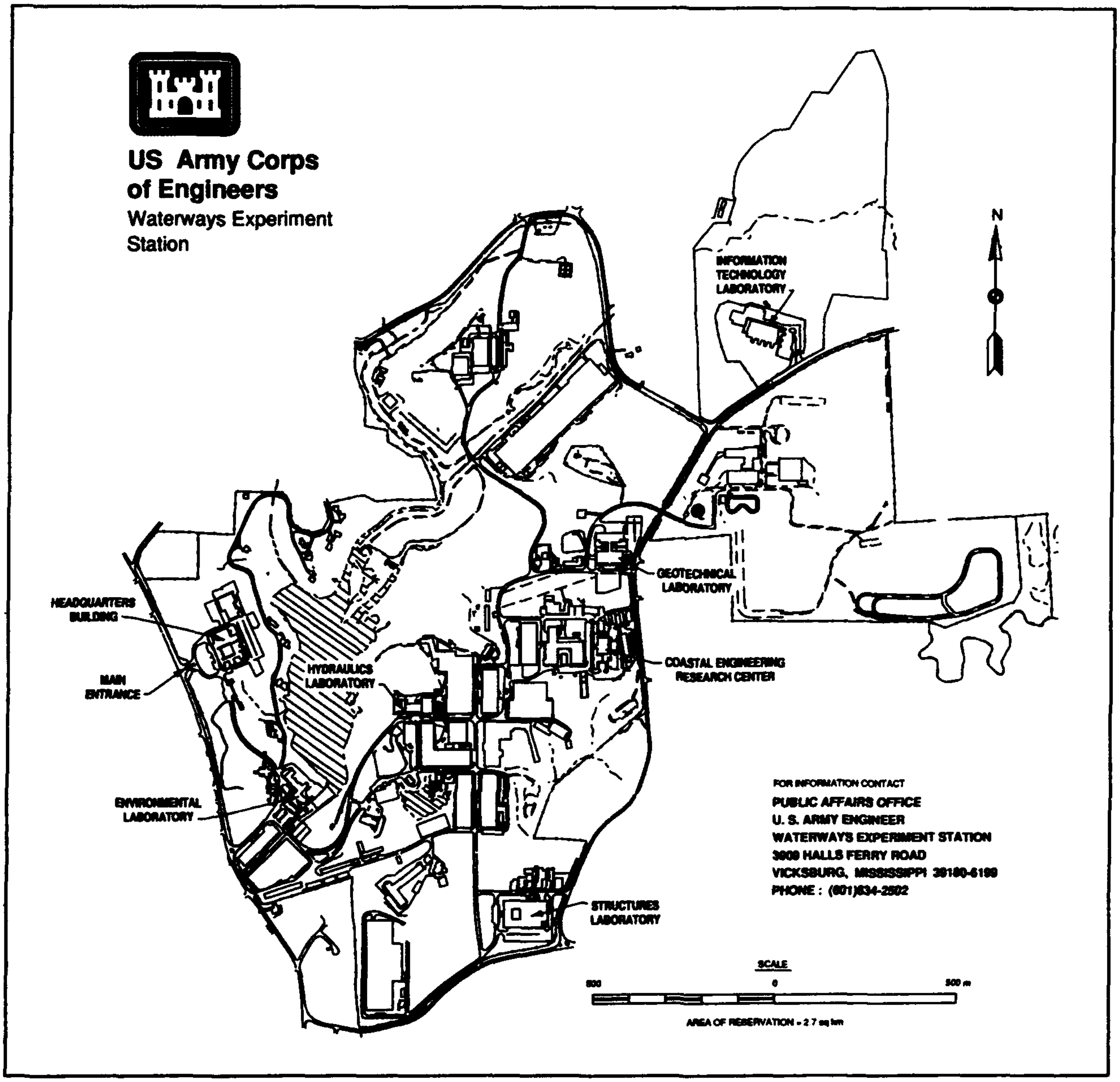

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PREFACE

This report is the 13th in a series of annual data summaries authorized by Headquarters, US Army Corps of Engineers (HQUSACE), under Civil Works Research Work Unit 32525, "Field Research Facility Analysis," Coastal Flooding Program. Funds were provided through the US Army Engineer Waterways Experiment Station (WES), Coastal Engineering Research Center (CERC), under the program management of Ms. Carolyn M. Holmes, CERC. The HQUSACE Technical Monitors were Messrs. John H. Lockhart, Jr.; Barry W. Holliday; John G. Housley; and David A. Roellig.

Data for the report were collected and analyzed at the WES/CERC Field Research Facility (FRF) in Duck, NC. The report was prepared by Mr. Michael W. Leffler, FRF, under the direct supervision of Mr. William A. Birkemeier, Chief, FRF Group, Engineering Development Division (EDD), and Mr. Thomas W. Richardson, Chief, EDD; and under the general supervision of Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., Director and Assistant Director, CERC, respectively. Mr. Kent K. Hathaway, FRF, assisted with instrumentation, and Mr. Brian L. Scarborough, FRF, assisted with data collection. Messrs. Clifford F. Baron, Stephen T. Blanchard, Matthew E. Cahur, Jonathan J. Lee, and Mohsen Alhaddad, and Mses. Judy H. Roughton and Juliana Atmadja assisted with data analysis at the FRF. The National Oceanic and Atmospheric Administration/National Ocean Service maintained the tide gage and provided statistics for summarization.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Leonard G. Hassell, EN.

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* A limited number of copies of Appendixes C-E (Volume II) were published under separate cover. Copies are available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

ANNUAL DATA SUMMARY FOR 1991
CERC FIELD RESEARCH FACILITY

PART I: INTRODUCTION

Background

1. The US Army Engineer Waterways Experiment Station (WES), Coastal Engineering Research Center's (CERC's) Field Research Facility (FRF), located on 0.7 km^2 at Duck, NC (Figure 1), consists of a 561-m-long research pier and accompanying office and field support buildings. The FRF is located near the middle of Currituck Spit along a 100-km unbroken stretch of shoreline extending south of Rudee Inlet, VA, to Oregon Inlet, NC. The FRF is bordered by the Atlantic Ocean to the east and Currituck Sound to the west. The facility is designed to (a) provide a rigid platform from which waves, currents, water levels, and bottom elevations can be measured, especially during severe storms; (b) provide CERC with field experience and data to complement laboratory and analytical studies and numerical models; (c) provide a manned field facility for testing new instrumentation; and (d) serve as a permanent field base of operations for physical and biological studies of the site and adjacent region.

2. The research pier is a reinforced concrete structure supported on 0.9-m-diam steel piles spaced 12.2 m apart along the pier's length and 4.6 m apart across the width. The piles are embedded approximately 20 m below the ocean bottom. The pier deck is 6.1 m wide and extends from behind the dune-line to about the 6-m water depth contour at a height of 7.8 m above the National Geodetic Vertical Datum (NGVD). The pilings are protected against sand abrasion by concrete erosion collars and against corrosion by a cathodic system.

3. An FRF Measurements and Analysis Program has been established to collect basic oceanographic and meteorological data at the site, reduce and analyze these data, and publish the results.

4. This report, which summarizes data for 1991, continues a series of reports begun in 1977.

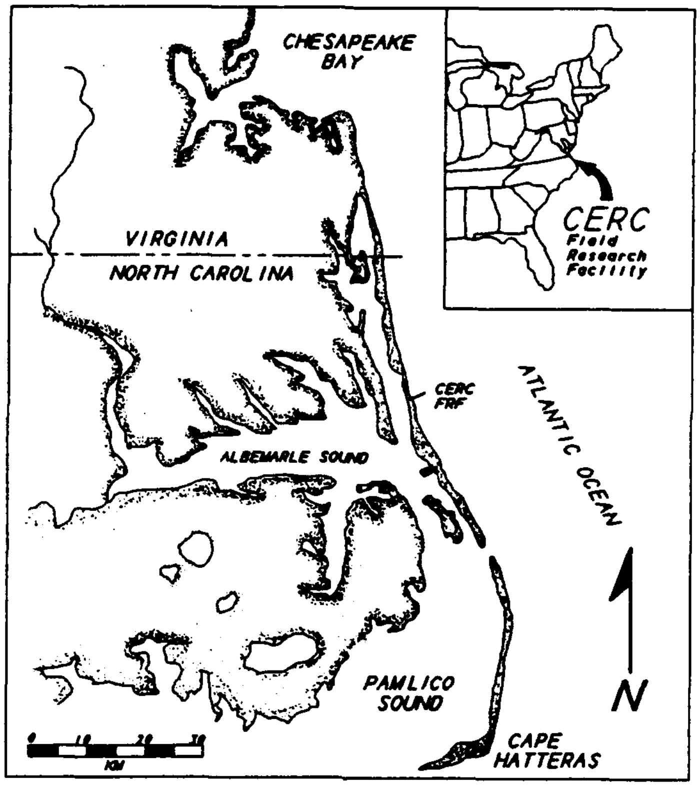

Figure 1. FRF location map

Organization of Report

5. This report is organized into nine parts and five appendixes. Part I is an introduction; Parts II through VIII discuss the various data collected during the year; and Part IX describes the storms that occurred. Appendix A presents the bathymetric surveys, Appendix B summarizes deepwater wave statistics, and Appendixes C through E (published under separate cover as Volume II) contain summary statistics for other gages.

6. In each part of this report, the respective instruments used for monitoring the meteorological or oceanographic conditions are briefly described, along with data collection and analysis procedures and data results. The instruments were interfaced with the primary data acquisition system, a Digital Equipment Corporation (Maynard, MA) VAX-11/750 minicomputer located in the FRF laboratory building. More detailed explanations of the design and the operation of the instruments may be found in Miller (1980). Readers' comments on the format and usefulness of the data presented are encouraged.

Availability of Data

7 Table 1 summarizes the available data. In addition to the wave data summaries in the main text, more extensive summaries for each of the wave gages are provided in Appendixes B through E.

Table 1

1991 Data Availability

	Gage	Jan					Feb				Mar				Apr					May				Jun				Jul					Aug				Sep				Oct					Nov				Dec			
	ID	1	2	3	4	5	1	2	3	4	1	2	3	4	1	2	3	4	5	1	2	3	4	1	2	3	4	1	2	3	4	5	1	2	3	4	1	2	3	4	1	2	3	4	5	1	2	3	4	1	2	3	4
Weather																																																					
Anemometer	932	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*
Atmospheric Pres.	616	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*
Air Temperature	624	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	-	*	*	*	*	*	*	*	*	*	*	*	*	*
Precipitation	604	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Waves																																																					
Offshore Waverider	630	*	/	/	-	-	-	-	-	-	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	/	-	-
Pressure Gage	111	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Pier End	625	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Pier Nearshore	645	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Currents																																																					
Pier End		*	*	*	*	/	*	/	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Pier Nearshore		*	*	*	*	/	/	/	*	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*	*	*	*	*	*	*	*	*
Beach		/	/	*	*	/	/	/	/	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	*	*	*	/	/	/	/	*	*	*	*	*	/	/	/	/	*	/	-	/	/	/	*	/	*
Pier End Tide Gage		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	/	*	*	*	*	*	*	*	*	/	*	*	*	*	*	/	/	*	*	/	*	*	*	*	*	/	/	*	*
Water Characteristics																																																					
Temperature		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Visibility		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	/	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Density		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	-	-	-	-	-	/	*	*	*	*	*	*
Bathymetric Surveys				*										*				*					*				*					*				*				*				*		*	*					*	
Photography																																																					
Beach		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	-	-	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	/	-	-	/	*	*	*	*	*	/	*
Aerial			*																																																		

Notes: * Full week of data obtained.
/ Less than 7 days of data obtained.
- No data obtained.

8. The annual data summary herein summarizes daily observations by month and year to provide basic data for analysis by users. Daily measurements and observations have already been reported in a series of monthly Preliminary Data Summaries (FRF 1991). If individual data for the present year are needed, the user can obtain detailed information (as well as the monthly and previous annual reports) from the following address:

USAE Waterways Experiment Station
Coastal Engineering Research Center
Field Research Facility
1261 Duck Rd.
Kitty Hawk, NC 27949-4472

Although the data collected at the FRF are designed primarily to support ongoing CERC research, use of the data by others is encouraged. Tidal data other than the summaries in this report can be obtained directly from the following address:

National Oceanic and Atmospheric Administration
National Ocean Service
ATTN: Tide Analysis Branch
Rockville, MD 20852

A complete explanation of the exact data desired for specific dates and times will expedite filling any request; an explanation of how the data will be used will help CEIAC or the National Oceanic and Atmospheric Administration (NOAA)/National Ocean Service (NOS) determine whether other relevant data are available. For information regarding the availability of data for all years, contact the FRF at 919-261-3511. Costs for collecting, copying, and mailing will be borne by the requester.

PART II: METEOROLOGY

9. This section summarizes the meteorological measurements made during the current year and in combination with all previous years. Meteorological measurements during storms are given in Part IX.

10. Mean air temperature, atmospheric pressure, and wind speed and direction were computed for each data file, which consisted of data sampled two times per second for 34 min every 6 hr beginning at or about 0100, 0700, 1300, and 1900 hr eastern standard time (EST); these hours correspond to the time that the National Weather Service (NWS) creates daily synoptic weather maps. During storms, data recordings were made more frequently. Meteorological data are summarized in Table 2.

Table 2

Meteorological Statistics

	Mean Air Temperature deg C		Mean Atmospheric Pres. mb		Precipitation, mm				Wind Resultants			
									1991		1980-1991	
					1991	1978-1991						
Month	1991	1983-1991	1991	1983-1991	Total	Mean	Maxima	Minima	Speed m/sec	Direction deg	Speed m/sec	Direction deg
Jan	7.3	5.9	1018.2	1017.9	142	101	180	44	2.6	341	2.3	333
Feb	7.8	6.8	1015.5	1017.5	8	72	113	20	2.0	306	1.7	342
Mar	11.2	9.7	1009.4	1016.2	186	100	206	35	2.0	268	1.4	355
Apr	15.0	13.7	1015.4	1013.8	73	97	182	0	0.3	322	0.3	328
May	22.6	19.2	1015.9	1015.8	7	72	239	20	1.2	156	0.6	187
Jun	26.8	23.8	1013.9	1015.3	59	86	136	27	0.6	92	1.0	198
Jul	29.4	26.4	1012.9	1016.0	150	99	275	19	2.4	217	1.8	210
Aug	26.1	25.9	1014.8	1016.0	114	98	221	30	0.6	159	0.5	97
Sep	25.7	22.8	1017.6	1017.6	7	77	226	5	2.1	63	2.0	40
Oct	21.5	18.2	1016.8	1019.1	124	70	143	17	2.6	15	2.3	26
Nov	16.8	13.6	1018.4	1018.3	46	87	145	26	1.7	321	1.7	344
Dec	9.8	8.1	1019.2	1019.5	97	66	131	4	2.4	294	2.1	328
Average	18.3	16.2	1015.7	1016.9	84	85			0.7	318	0.8	351
Total					1013	1025						

Air Temperature

11. The FRF enjoys a typical marine climate that moderates the temperature extremes of both summer and winter.

Measurement instruments

12. A Yellow Springs Instrument Company, Inc. (YSI) (Yellow Springs, OH) electronic temperature probe with analog output interfaced to the FRF's computer was operated beside the NWS's meteorological instrument shelter located 43 m behind the dune (Figure 2). To ensure proper temperature

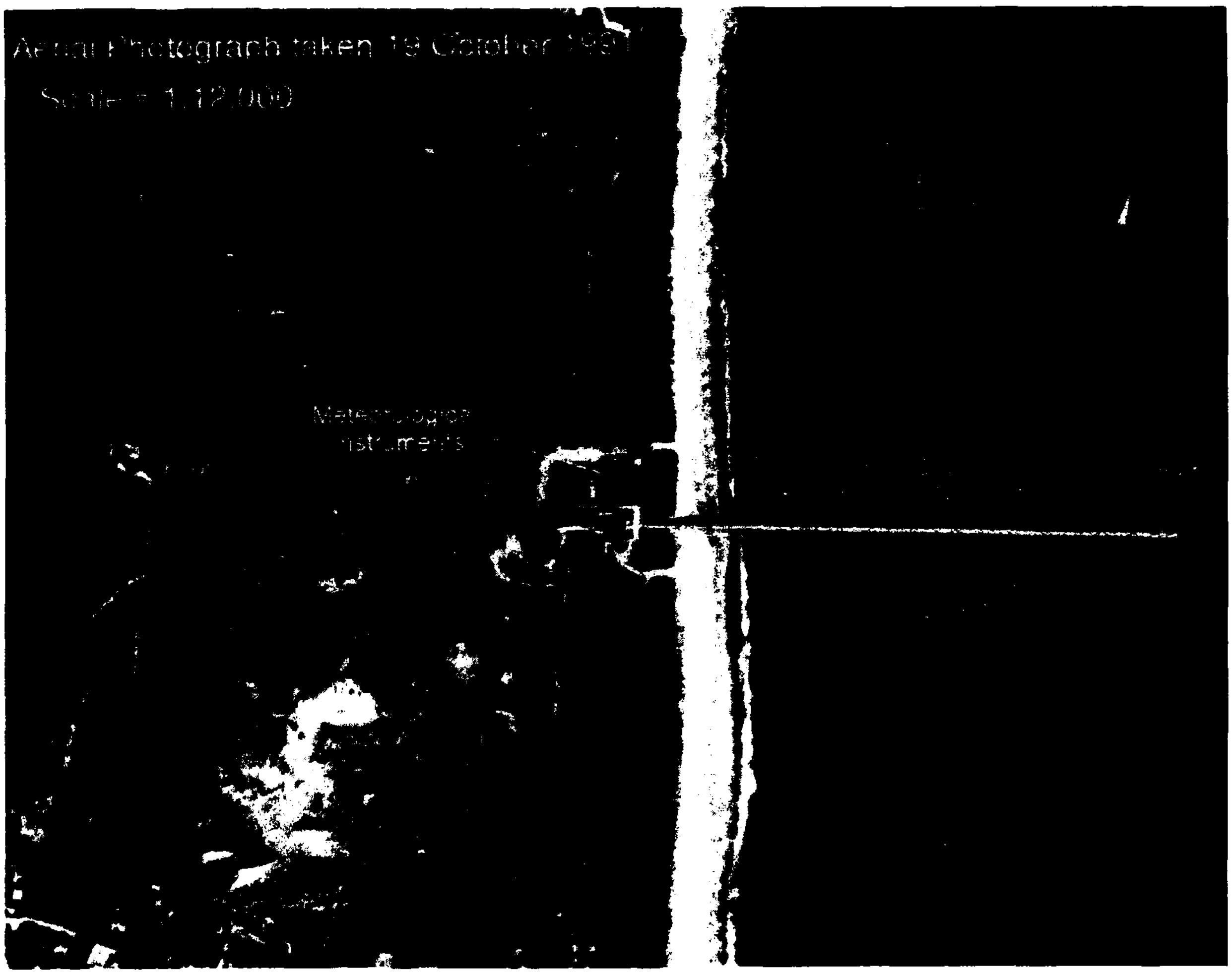

Figure 2. FRF gage locations

readings, the probe was installed 3 m above ground inside a "coolie hat" to shade it from direct sun, yet provide proper ventilation.

Results

13. Daily and average air temperature values are tabulated in Table 2 and shown in Figure 3.

Atmospheric Pressure

Measurement instruments

14. Electronic atmospheric pressure sensor. Atmospheric pressure was measured with a YSI electronic sensor with analog output located in the laboratory building at 9 m above NGVD. Data were recorded on the FRF computer. Data from this gage were compared with those from an NWS aneroid barometer to ensure proper operation.

15. Microbarograph. A Weathertronics, Incorporated (Sacramento, CA) recording aneroid sensor (microbarograph) located in the laboratory building also was used to continuously record atmospheric pressure variation.

16. The microbarograph was compared daily with the NWS aneroid barometer, and adjustments were made as necessary. Maintenance of the microbarograph consisted of inking the pen, changing the chart paper, and winding the clock every 7 days. During the summer, a meteorologist from the NWS checked and verified the operation of the barometer.

17. The microbarograph was read and inspected daily using the following procedure:

a. The pen was zeroed (where applicable).

b. The chart time was checked and corrected, if necessary.

c. The daily reading was marked on the chart for reference.

d. The starting and ending chart times were recorded, as necessary.

e. New charts were installed, when needed.

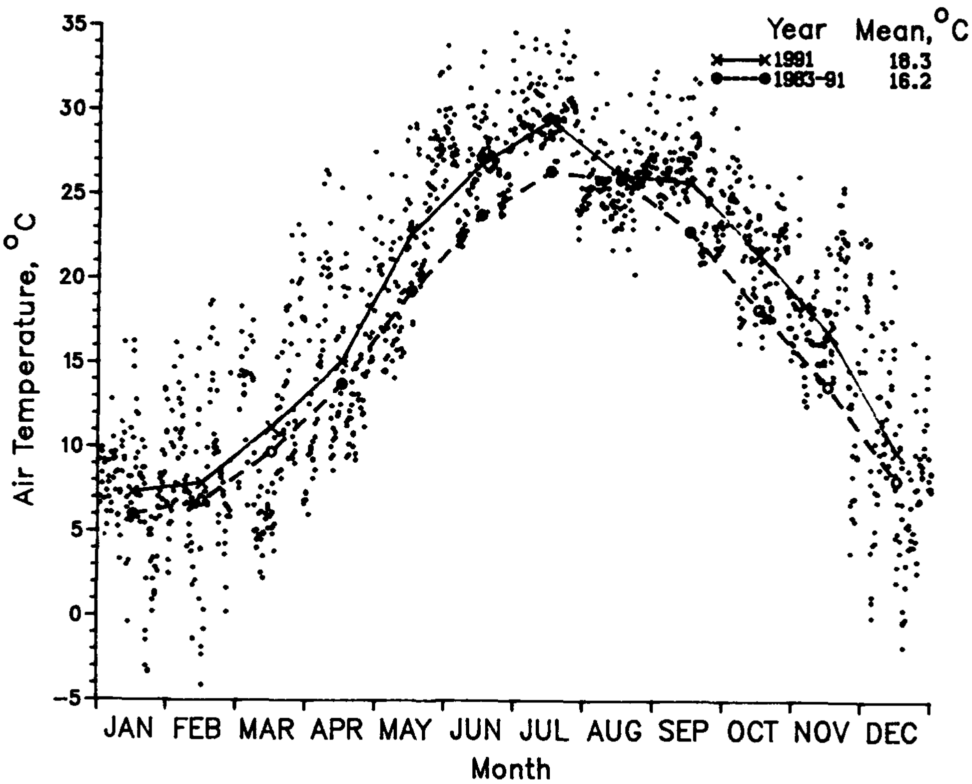

Figure 3. Daily air temperature values with monthly means

Results

18. Daily and average atmospheric pressure values are presented in Figure 4, and summary statistics are presented in Table 2.

Precipitation

19. Precipitation is generally well distributed throughout the year. Precipitation from mid-latitude cyclones (northeasters) predominates in the winter, whereas local convection (thunderstorms) accounts for most of the summer rainfall.

Measurement instruments

20. Electronic rain gage. A Belfort Instrument Company (Baltimore, MD) 30-cm weighing rain gage, located near the instrument shelter 47 m behind the dune, measured daily precipitation. According to the manufacturer, the instrument's accuracy was 0.5 percent for precipitation amounts less than

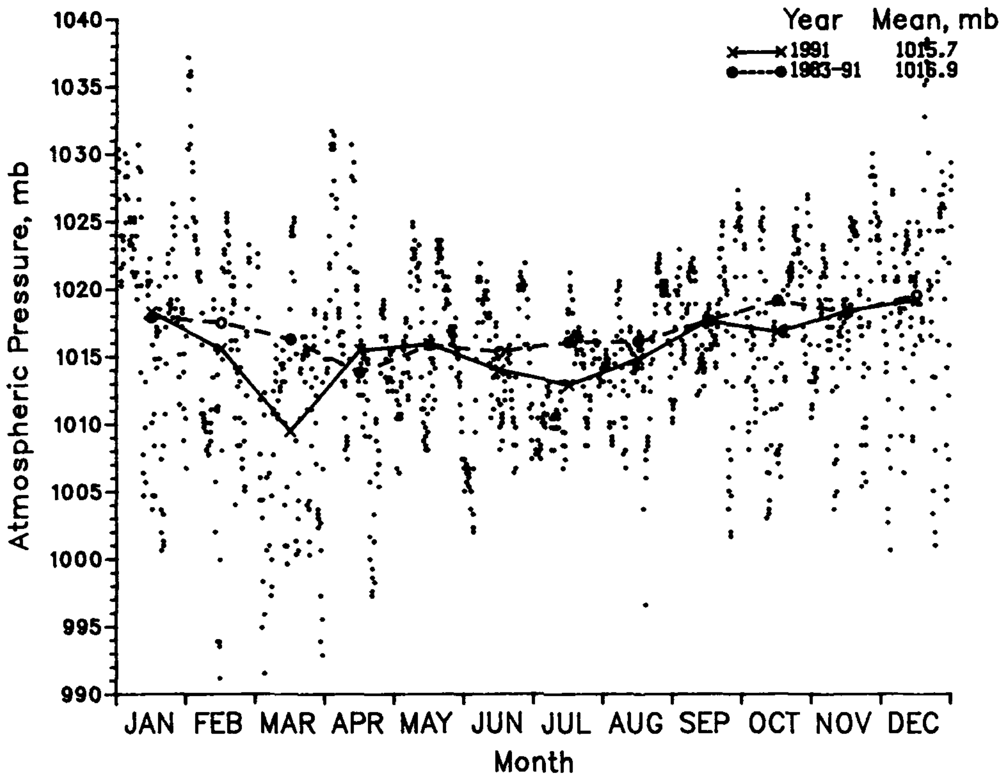

Figure 4. Daily barometric pressure values with monthly means

15 cm and 1.0 percent for amounts greater than 15 cm.

21. The rain gage was inspected daily, and the analog chart recorder was maintained by procedures similar to those for the microbarograph.

22. Plastic rain gage. An Edwards Manufacturing Company (Alberta Lea, MN) True Check 15-cm-capacity clear plastic rain gage with a 0.025-cm resolution was used to monitor the performance of the weighing rain gage. This gage was located near the weighing gage, and the gages were compared on a daily basis. Very few discrepancies were identified during the year.

Results

23. Daily and monthly average precipitation values are shown in Figure 5. Statistics of total precipitation for each month during this year and average totals for all years combined are presented in Table 2.

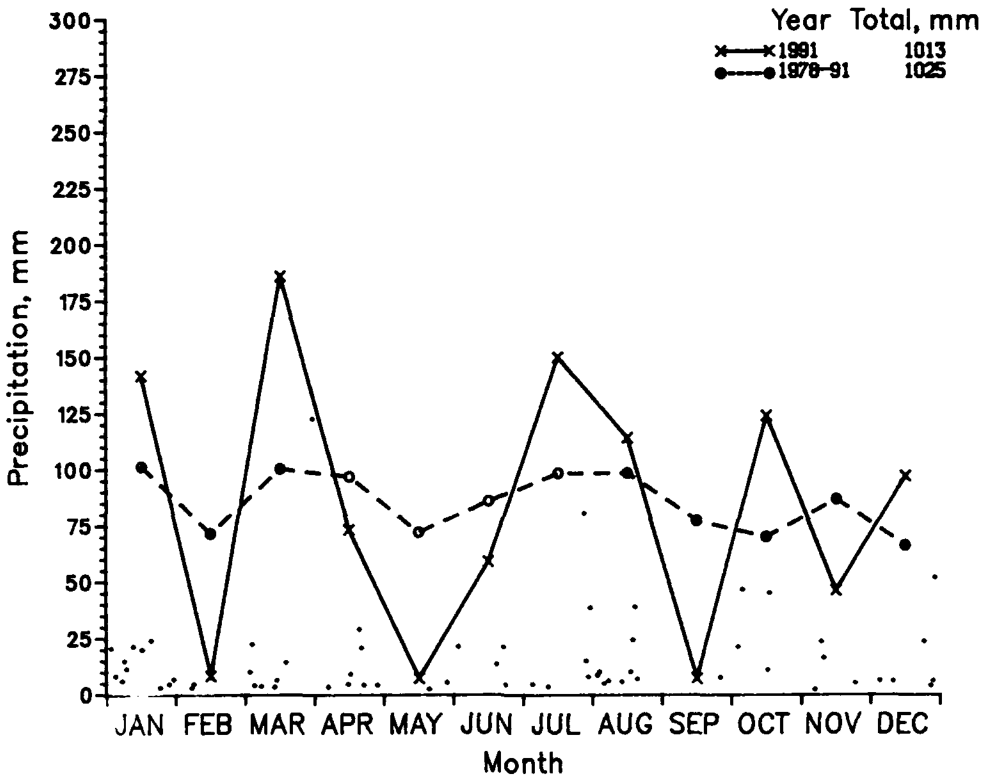

Figure 5. Daily precipitation values with monthly totals

Wind Speed and Direction

24. Winds at the FRF are dominated by tropical maritime air masses that create low to moderate, warm southern breezes; arctic and polar air masses that produce cold winds from northerly directions; and smaller scale cyclonic, low pressure systems, which originate either in the tropics (and move north along the coast) or on land (and move eastward offshore). The dominant wind direction changes with the season, being generally from northern directions in the fall and winter and from southern directions in the spring and summer. It is common for fall and winter storms (northeasters) to produce winds with average speeds in excess of 15 m/sec.

Measurement instrument

25. Winds were measured at the seaward end of the pier at an elevation of 19.1 m (Figure 2) using a Weather Measure Corporation (Sacramento, CA) Skyvane Model W102P anemometer. Wind speed and direction data were collected on the FRF computer. The anemometer manufacturer specifies an accuracy of ± 0.45 m/sec below 13 m/sec and 3 percent at speeds above 13 m/sec, with a

threshold of 0.9 m/sec. Wind direction accuracy is ± 2 deg, with a resolution of less than 1 deg. The anemometer is calibrated annually at the National Bureau of Standards in Gaithersburg, MD, and is within the manufacturer's specifications.

Results

26. Annual and monthly joint probability distributions of wind speed versus direction were computed. Wind speeds were resolved into 3-m/sec intervals, whereas the directions were at 22.5-deg intervals (i.e., 16-point compass direction specifications). These distributions are presented as wind "roses," such that the length of the petal represents the frequency of occurrence of wind blowing from the specified direction, and the width of the petal is indicative of the speed. Resultant directions and speeds were also determined by vector-averaging the data (see Table 2). Wind statistics are presented in Figures 6, 7, and 8.

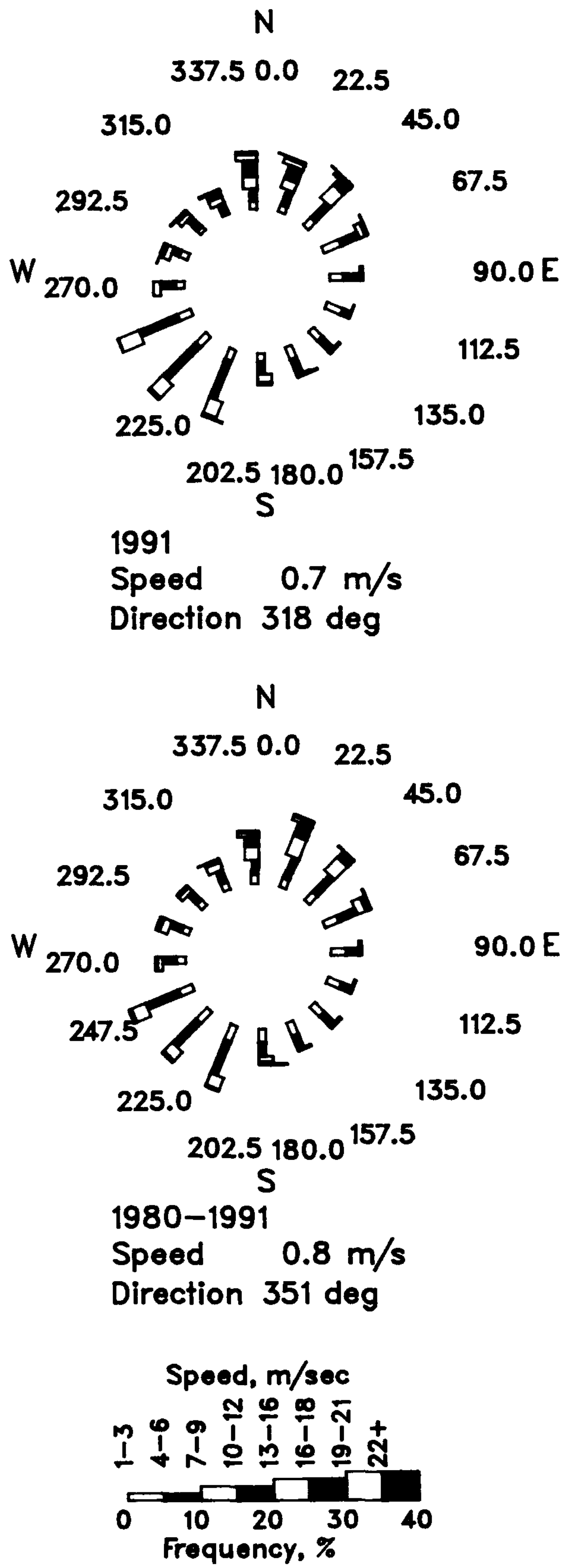

Figure 6. Annual wind roses

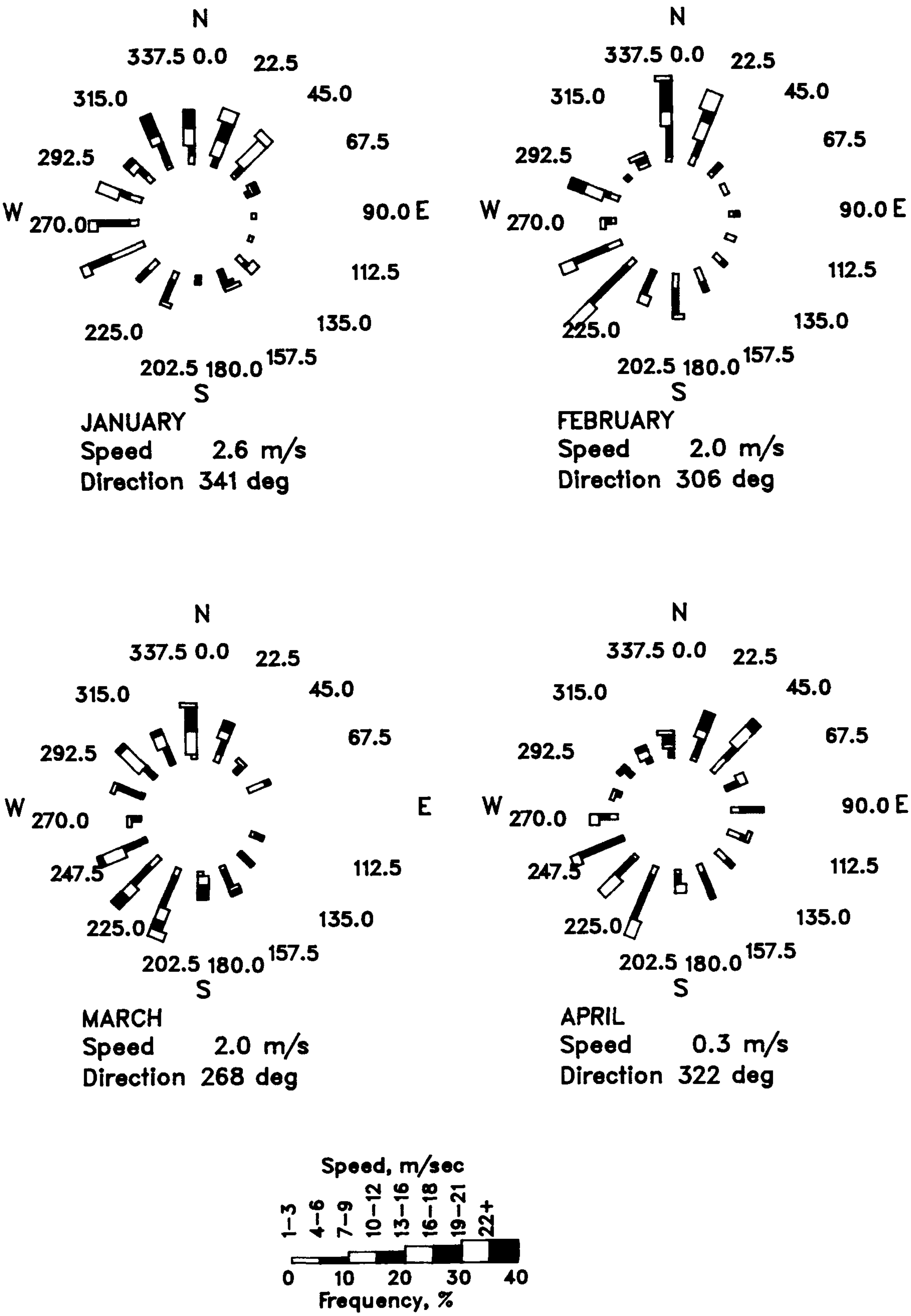

Figure 7. Monthly wind roses for 1991
(Sheet 1 of 3)

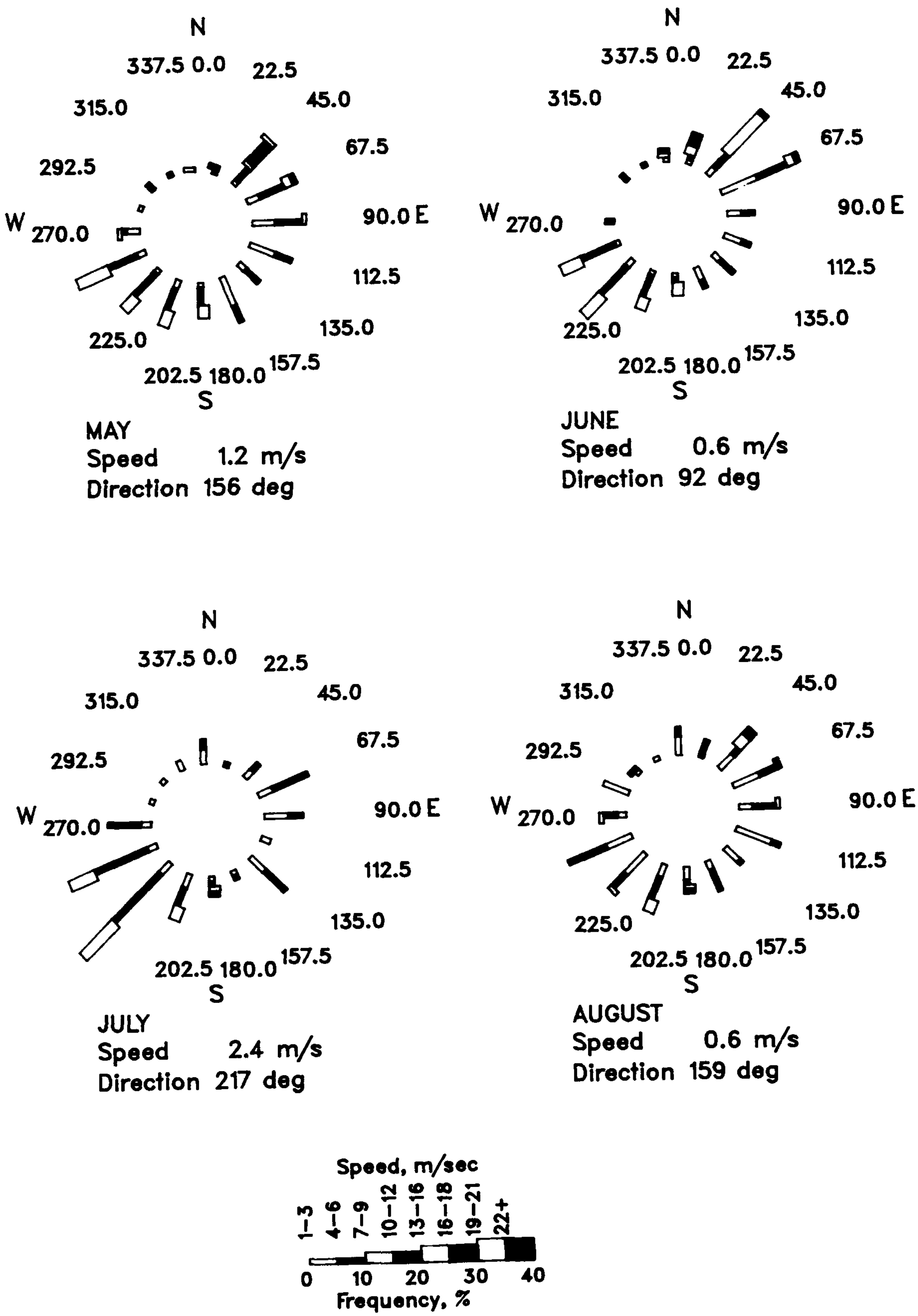

Figure 7. (Sheet 2 of 3)

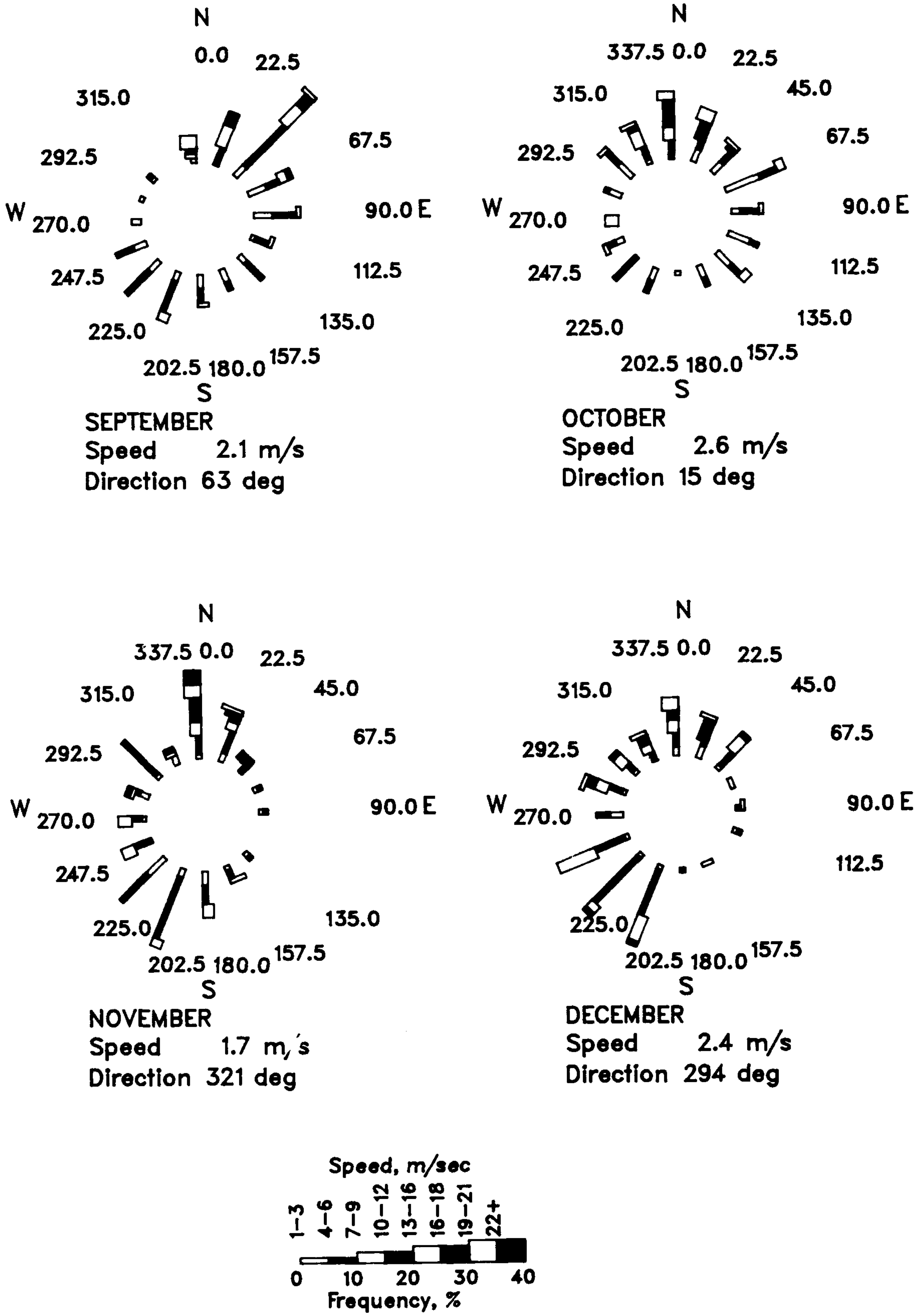

Figure 7. (Sheet 3 of 3)

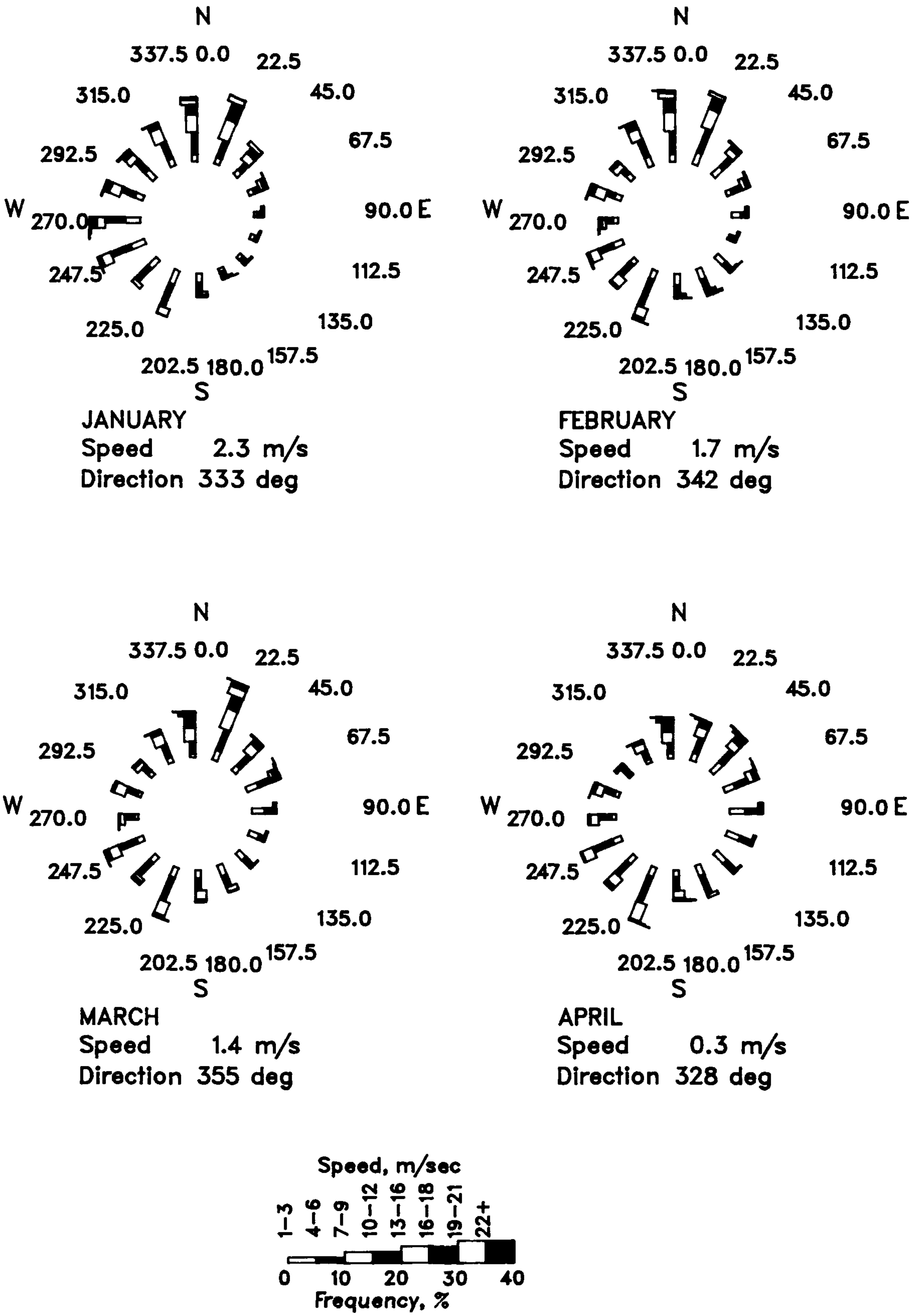

Figure 8. Monthly wind roses for 1980 through 1991 (Sheet 1 of 3)

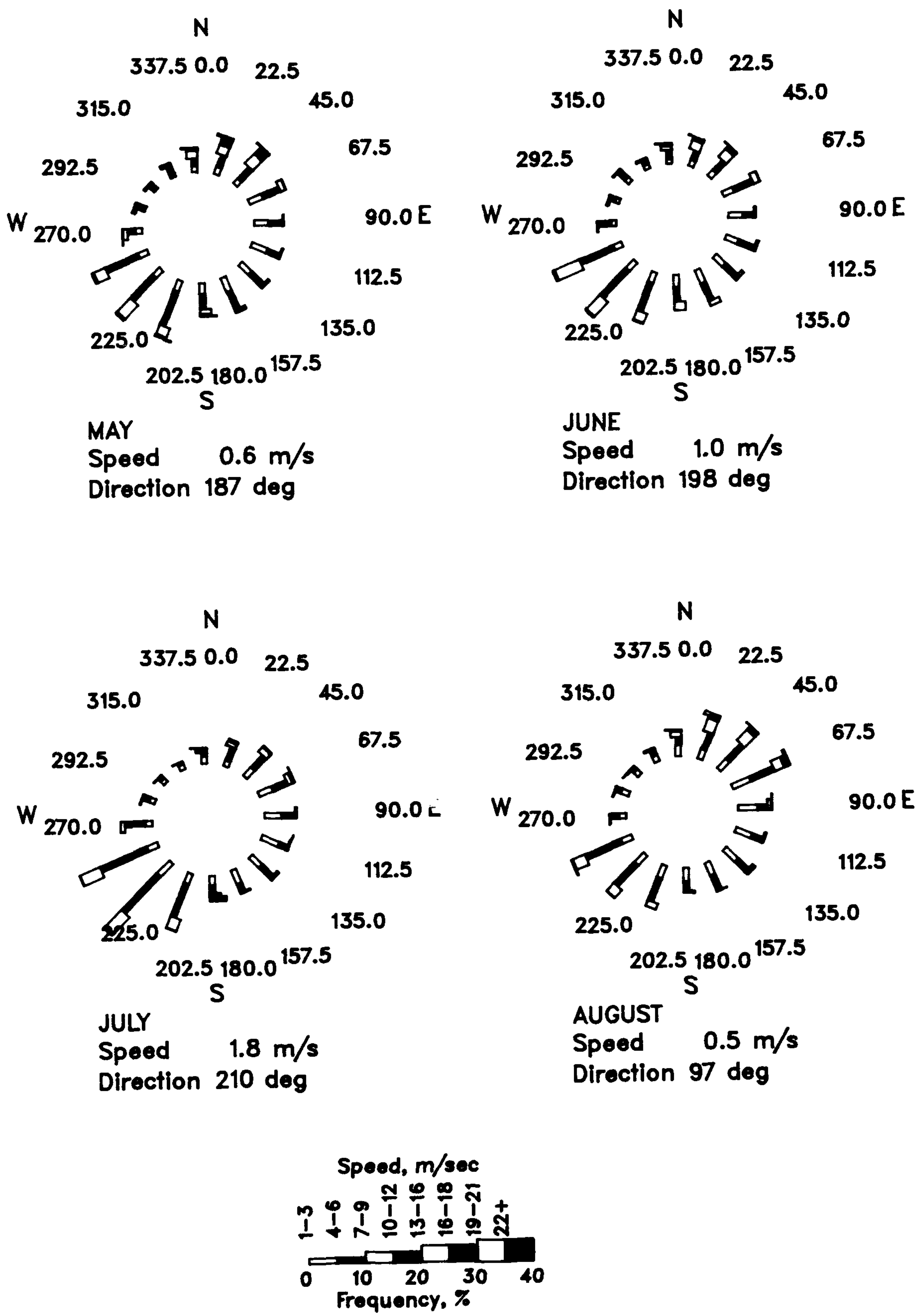

Figure 8. (Sheet 2 of 3)

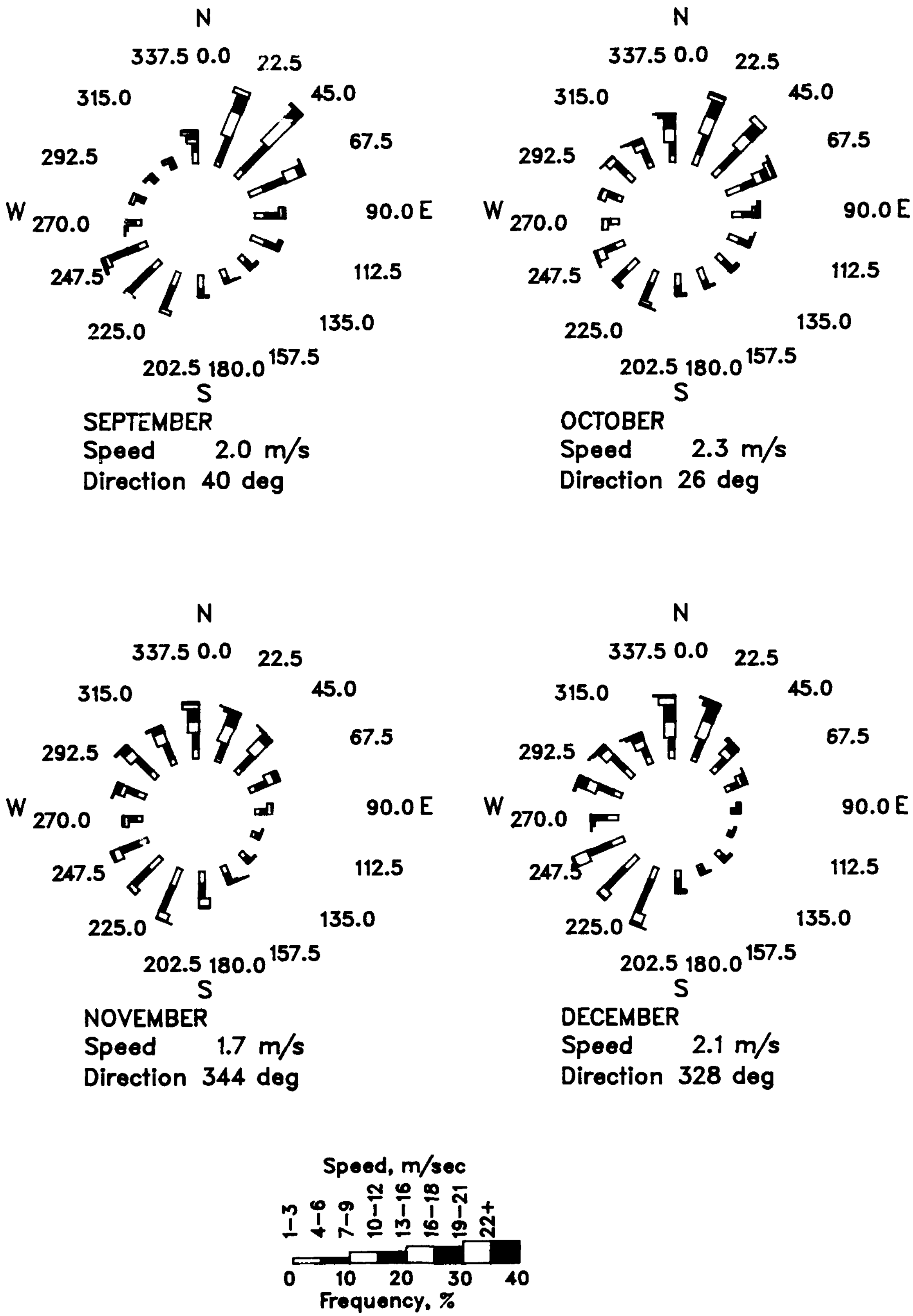

Figure 8. (Sheet 3 of 3)

PART III: WAVES

27. This section presents summaries of the wave data. A discussion of individual major storms is given in Part IX and contains additional wave data for times when wave heights exceeded 2 m at the seaward end of the FRF pier. Appendixes B through E provide more extensive data summaries for each gage, including height and period distributions, wave direction distributions, persistence tables, and spectra during storms.

28. Wave directions (similar to wind directions) at the FRF are seasonally distributed. Waves approach most frequently from north of the pier in the fall and winter and south of the pier in the summer, with the exception of storm waves that approach twice as frequently from north of the pier. Annually, waves are approximately evenly distributed between north and south (resultant wave direction being almost shore-normal).

Measurement Instruments

29. The wave gages included two wave staff gages (Gages 645 and 625), one buoy gage (Gage 630), and one pressure gage (Gage 111) as shown in Figure 2 and located as follows:

Gage Type/Number	Distance Offshore from Baseline	Water Depth m	Operational Period
Continuous wire (645)	238 m	3.5	11/84-12/91
Continuous wire (625)	567 m	8	11/78-12/91
Accelerometer buoy (630)	6 km	18	11/78-12/91
Pressure gage (111)	1 km	9	09/86-12/91

Staff gages

30. Two Baylor Company (Houston, TX) parallel cable inductance wave gages (Gage 645 at sta 7+80 and Gage 625 at sta 19+00 (Figure 2)) were mounted on the FRF pier. Rugged and reliable, these gages require little maintenance except to keep tension on the cables and to remove any material that may cause an electrical short between them. They were calibrated prior to installation by creating an electrical short between the two cables at known distances along the cable and recording the voltage output. Electronic signal conditioning amplifiers are used to ensure that the output signals from the gages are within a 0- to 5-V range. Manufacturer-stated gage accuracy is about 1.0 percent, with a 0.1-percent full-scale resolution; full scale is 14 m for Gage 625 and 8.2 m for Gage 645. These gages are susceptible to

lightning damage, but protective measures have been taken to minimize such occurrences. A more complete description of the gages' operational characteristics is given by Grogg (1986).

Buoy gage

31. One Datawell Laboratory for Instrumentation (Haarlem, The Netherlands) Waverider buoy gage (Gage 630) measures the vertical acceleration produced by the passage of a wave. The acceleration signal is double-integrated to produce a displacement signal transmitted by radio to an onshore receiver. The manufacturer stated that wave amplitudes are correct to within 3 percent of their actual value for wave frequencies between 0.065 and 0.500 Hz (corresponding to 15- to 2-sec wave periods). The manufacturer also specified that the error gradually increased to 10 percent for wave periods in excess of 20 sec. The results in this report were not corrected for the manufacturer's specified amplitude errors. However, the buoy was calibrated semiannually to ensure that it was within the manufacturer's specification.

Pressure gage

32. One Senso-Metrics, Incorporated (Simi Valley, CA), pressure transduction gage (Gage 111) installed near the ocean bottom measures the pressure changes produced by the passage of waves creating an output signal that is linear and proportional to pressure when operated within its design limits. Predeployment and postdeployment precision calibrations are performed at the FRF using a static deadweight tester. The sensor's range is 0 to 25 psi (equivalent to 0- to 17-m seawater) above atmospheric pressure with a manufacturer-stated accuracy of ± 0.25 percent. Copper scouring pads are installed at the sensor's diaphragm to reduce biological fouling, and the system is periodically cleaned by divers.

Digital Data Analysis and Summarization

33. The data were collected, analyzed, and stored on magnetic tape using the FRF's VAX computer. Data sets were normally collected every 6 hr. During storms, the collection was at 3-hr intervals. For each gage, a data set consisted of four contiguous records of 4,096 points recorded at 0.5 Hz (approximately 34 min long), for a total of 2 hr and 16 min. Analysis was performed on individual 34-min records.

34. The analysis program computes the first moment (mean) and the

second moment about the mean (variance) and then edits the data by checking for "jumps," "spikes," and points exceeding the voltage limit of the gage. A jump is defined as a data value greater than five standard deviations from the previous data value, whereas a spike is a data value more than five standard deviations from the mean. If less than five consecutive jumps or spikes are found, the program linearly interpolates between acceptable data and replaces the erroneous data values. The editing stops if the program finds more than five consecutive jumps or spikes, or more than a total of 100 bad points, or the variance of the voltage is below 1×10^{-5} squared volts. The statistics and diagnostics from the analysis are saved.

35. Sea surface energy spectra are computed from the edited time series. Spectral estimates are computed from smaller data segments obtained by dividing the 4,096-point record into several 512-point segments. The estimates are then ensemble-averaged to produce a more accurate spectrum. These data segments are overlapped by 50 percent (known as the Welch (1967) method) which has been shown to produce better statistical properties than nonoverlapped segments. The mean and linear trends are removed from each segment prior to spectral analysis. To reduce side-lobe leakage in the spectral estimates, a data window was applied. The first and last 10 percent of data points were multiplied by a cosine bell (Bingham, Godfrey, and Tukey 1967). Spectra were computed from each segment with a discrete Fast Fourier Transform and then ensemble-averaged. Sea surface spectra from subsurface pressure gages were obtained by applying the linear wave theory transfer function.

36. Unless otherwise stated, wave height in this report refers to the energy-based parameter H_{mo} defined as four times the zeroth moment wave height of the estimated sea surface spectrum (i.e., four times the square root of the variance) computed from the spectrum passband. Energy computations from the spectra are limited to a passband between 0.05 and 0.50 Hz for surface gages and between 0.05 Hz and a high-frequency cutoff for subsurface gages. This high-frequency limit is imposed to eliminate aliased energy and noise measurements from biasing the computation of H_{mo} and is defined as the frequency where the linear theory transfer function is less than 0.1 (spectral values are multiplied by 100 or more). Smoother and more statistically significant spectral estimates are obtained by band-averaging contiguous spectral components (three components are averaged per band, producing a

frequency band width of 0.0117 Hz).

37. Wave period T_p is defined as the period associated with the maximum energy band in the spectrum, which is computed using a 3-point running average band on the spectrum. The peak period is reported as the reciprocal of the center frequency (i.e., T_p = 1/frequency) of the spectral band with the highest energy. A detailed description of the analysis techniques is presented in a report by Andrews (1987).*

Results

38. The wave conditions for the year are shown in Figure 9. For all four gages, the distributions of wave height for the current year and all years combined are presented in Figures 10 and 11, respectively. Distributions of wave period are presented in Figure 12.

39. Multiple-year comparisons of data for Gage 111 actually incorporate data for 1985 and 1986 from Gage 640 (a discontinued Waverider buoy previously located at the approximate depth and distance offshore of Gage 111) and data for 1987 from Gage 141, located 30 m south of Gage 111.

40. Refraction, bottom friction, and wave breaking contribute to the observed differences in height and period. During the most severe storms when the wave heights exceed 3 m at the seaward end of the pier, the surf zone (wave breaking) has been observed to extend past the end of the pier and occasionally 1 km offshore. This occurrence is a major reason for the differences in the distributions between Gage 630 and the inshore gages. The wave height statistics for the staff gage (Gage 645), located at the landward end of the pier, were considerably lower than those for the other gages. In all but the calmest conditions, this gage is within the breaker zone. Consequently, these statistics represent a lower energy wave climate.

41. Summary wave statistics for the current year and all years combined are presented for Gage 630 in Table 3.

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* M. E. Andrews. 1987. "Standard Wave Data Anfresis Procedures for Coastal Engineering Applications," unpublished report prepared for the US Army Engineer Waterways Experiment Station, Vicksburg, MS.

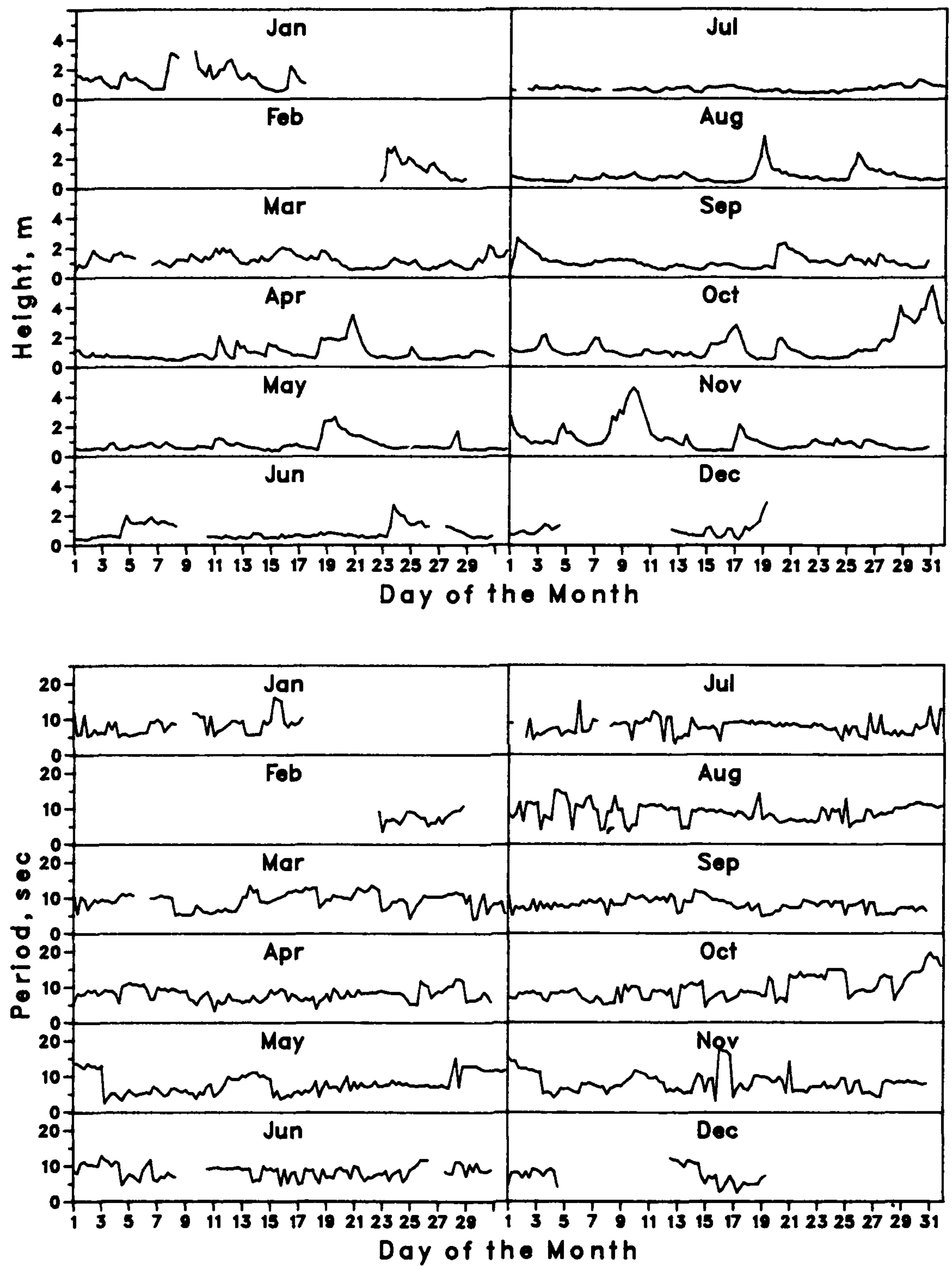


Figure 9. 1991 time histories of wave height and period for Gage 630

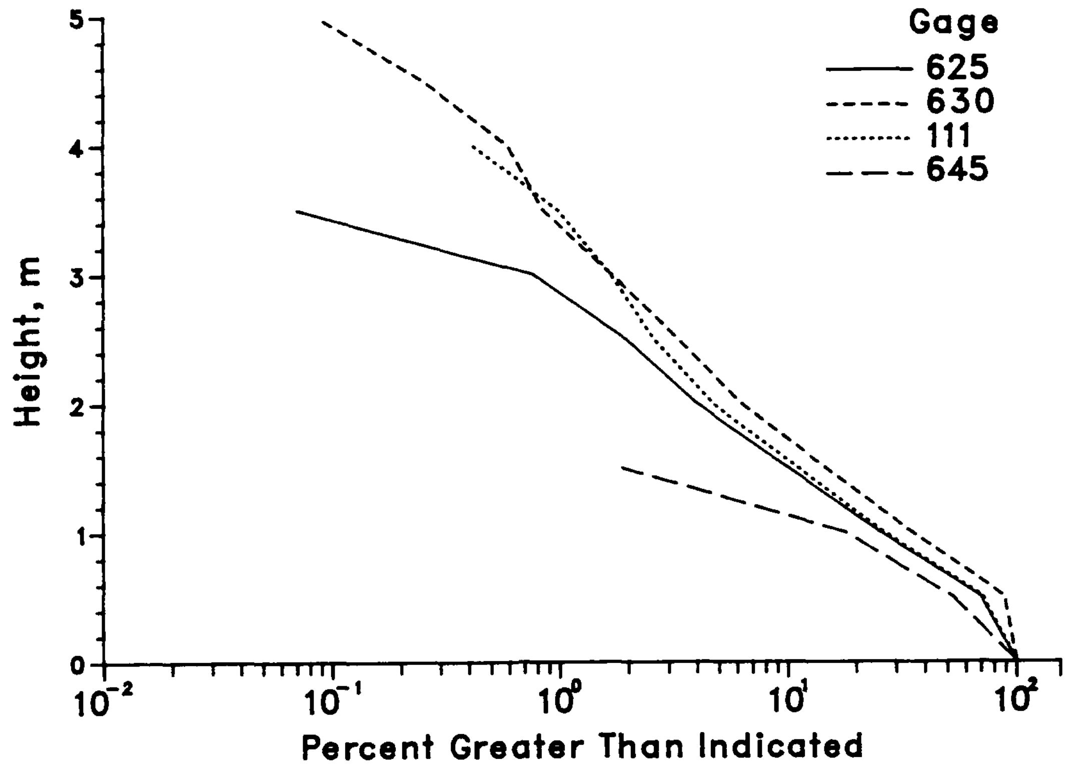


Figure 10. 1991 annual wave height distributions

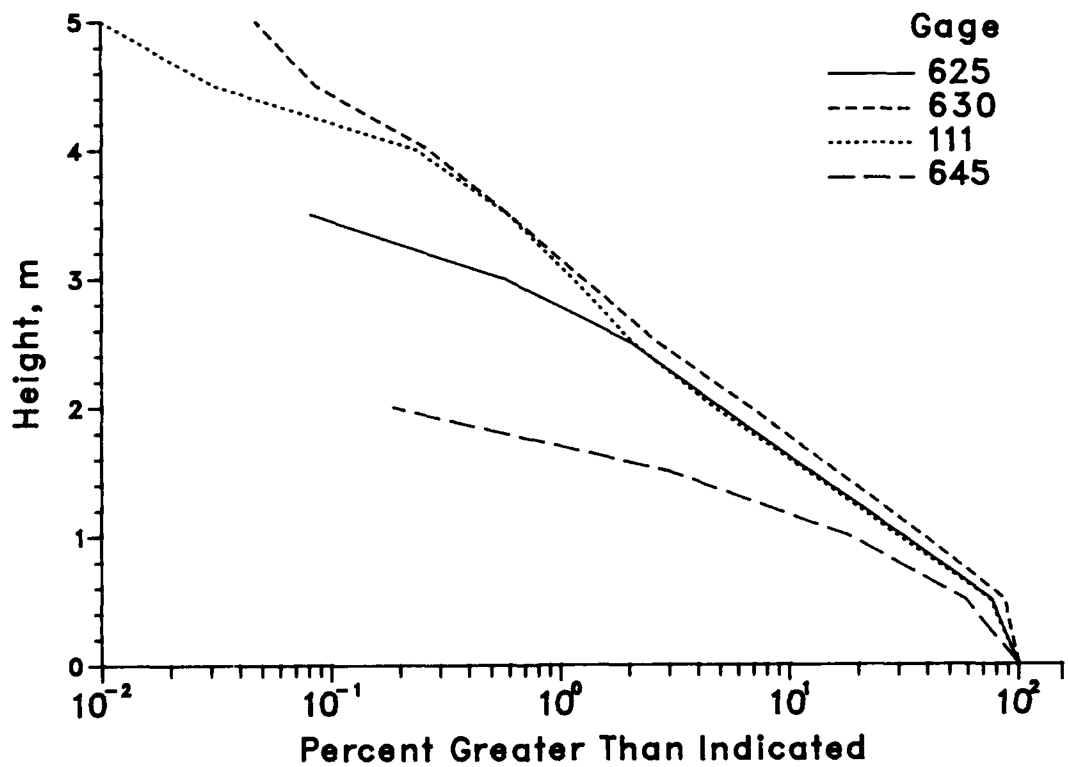


Figure 11. Annual distribution of wave heights for 1980 through 1991

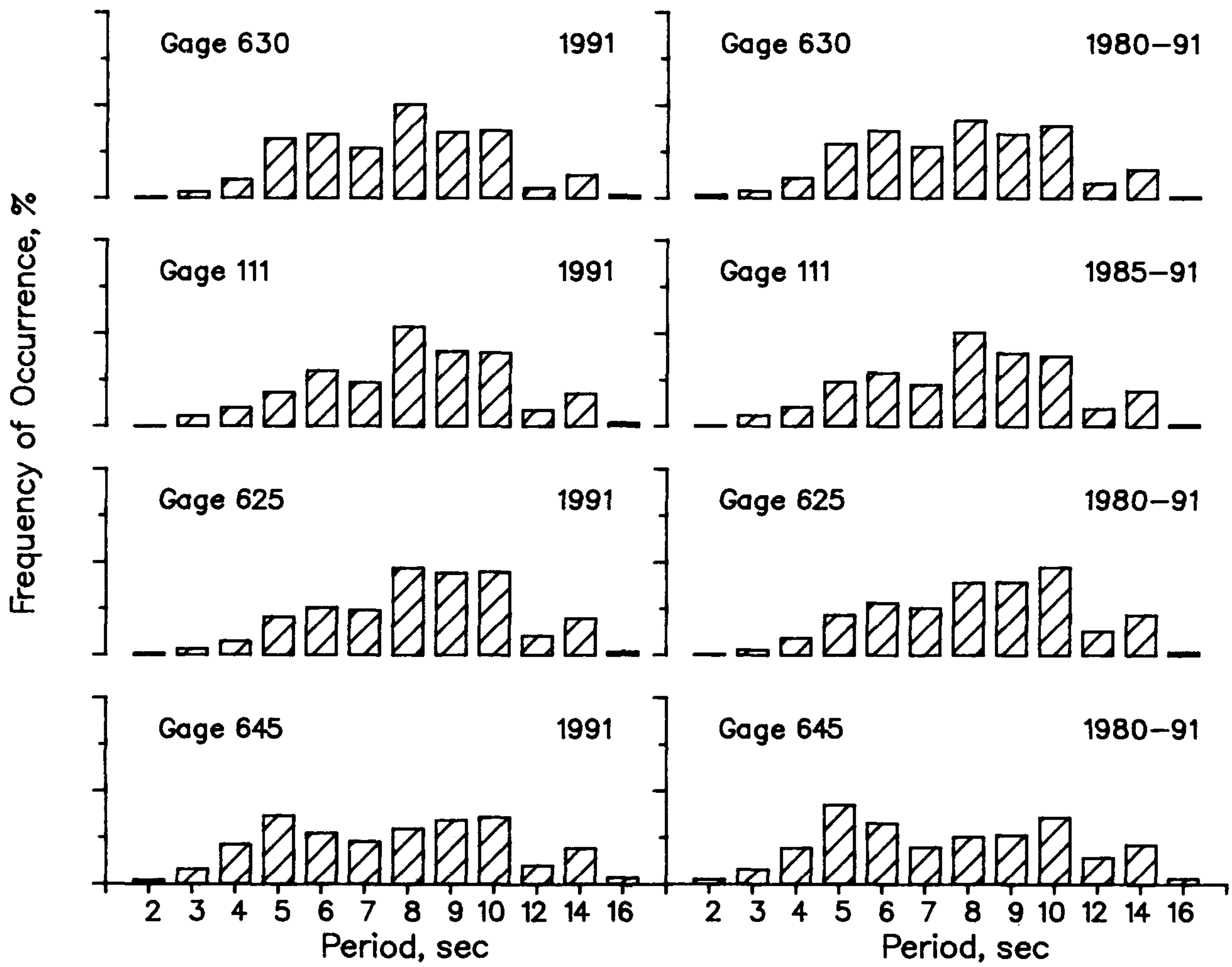


Figure 12. Annual wave period distributions for all gages

Table 3

Wave Statistics for Gage 630

	1991							1980-1991						
	Height				Period			Height				Period		
Month	Mean m	Std. Dev. m	Extreme m	Date	Mean sec	Std. Dev. sec	Number Obs.	Mean m	Std. Dev. m	Extreme m	Date	Mean sec	Std. Dev. sec	Number Obs.
Jan	1.5	0.7	3.2	9	8.0	2.5	61	1.2	0.7	4.5	1983	8.1	2.7	1255
Feb	1.4	0.7	2.8	23	7.5	1.7	25	1.2	0.7	5.1	1987	8.4	2.6	1146
Mar	1.2	0.5	2.1	30	9.2	2.4	118	1.2	0.7	4.7	1983	8.7	2.6	1358
Apr	1.0	0.6	3.5	20	7.9	1.8	120	1.0	0.6	5.0	1988	8.6	2.6	1327
May	0.8	0.5	2.6	19	7.8	2.9	122	0.9	0.5	3.3	1986	8.1	2.5	1351
Jun	0.9	0.5	2.7	23	8.4	1.9	106	0.8	0.4	2.7	1991	7.8	2.2	1244
Jul	0.7	0.2	1.3	30	7.8	2.1	116	0.7	0.3	2.1	1985	8.1	2.4	1280
Aug	0.8	0.5	3.5	19	8.9	2.5	123	0.8	0.5	3.6	1981	8.2	2.5	1303
Sep	1.1	0.5	2.6	1	8.1	1.7	119	1.1	0.6	6.1	1985	8.6	2.6	1310
Oct	1.4	1.0	5.4	31	9.7	3.4	122	1.3	0.7	5.4	1991	8.8	2.8	1361
Nov	1.1	0.9	4.6	9	8.2	2.9	118	1.1	0.7	4.6	1991	7.9	2.8	1155
Dec	1.0	0.5	2.9	19	7.5	2.6	41	1.2	0.8	5.6	1980	8.2	2.9	1108
Annual	1.1	0.6	5.4	Oct	8.3	2.6	1191	1.0	0.6	6.1	Sep 1985	8.3	2.6	15198

42. Annual joint distributions of wave height versus wave period for Gage 630 are presented for 1991 in Table 4, and for all years combined in Table 5. Similar distributions for the other gages are included in Appendixes B-E.

43. Annual distributions of wave directions (relative to true north) based on daily observations of direction at the seaward end of the pier and height from Gage 625 (or Gage 111 when data for Gage 625 were unavailable) are shown in Figure 13. Monthly wave "roses" for 1991 and all years combined are presented in Figures 14 and 15, respectively.

Table 4

Annual (1991) Joint Distribution of H_{mo} versus T_p for Gage 630*

	Period, sec												
Height, m	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	8	17	17	50	50	84	319	243	168	34	126	25	1141
0.50 - 0.99	17	118	285	596	655	579	982	840	974	101	218	.	5365
1.00 - 1.49	.	.	84	437	269	193	537	218	176	25	92	.	2031
1.50 - 1.99	.	.	17	176	227	101	92	76	101	17	34	.	841
2.00 - 2.49	.	.	.	25	118	50	42	25	25	8	.	.	293
2.50 - 2.99	.	.	.	.	50	50	34	.	.	8	17	.	159
3.00 - 3.49	.	.	.	.	8	25	.	8	8	17	8	8	82
3.50 - 3.99	.	.	.	.	.	.	8	.	.	8	8	.	24
4.00 - 4.49	.	.	.	.	.	.	8	8	8	.	.	8	32
4.50 - 4.99	.	.	.	.	.	.	.	8	.	.	.	8	16
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	8	8
Total	25	135	403	1284	1377	1082	2022	1426	1460	218	503	57	

* Percent occurrence (x100) of height and period.

Table 5

Annual (1980-1991) Joint Distribution of H_{mo} versus T_p for Gage 630 (All Years)*

	Period, sec												
Height, m	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	27	14	26	60	86	114	332	278	189	66	126	5	1323
0.50 - 0.99	37	136	255	509	592	526	882	744	801	140	229	16	4867
1.00 - 1.49	.	9	143	405	424	251	284	212	322	40	121	3	2214
1.50 - 1.99	.	.	13	164	245	111	83	78	126	32	72	4	928
2.00 - 2.49	.	.	1	24	95	67	54	37	59	27	36	1	401
2.50 - 2.99	.	.	.	1	12	32	18	13	32	10	24	1	143
3.00 - 3.49	.	.	.	.	1	12	12	12	14	5	8	1	65
3.50 - 3.99	.	.	.	.	.	1	6	7	11	4	5	.	34
4.00 - 4.49	.	.	.	.	.	.	2	4	7	1	3	1	18
4.50 - 4.99	.	.	.	.	.	.	.	1	2	.	.	1	4
5.00 - Greater	.	.	.	.	.	.	1	.	1	1	1	1	5
Total	64	159	438	1163	1455	1114	1674	1386	1564	326	625	34	

* Percent occurrence (x100) of height and period.

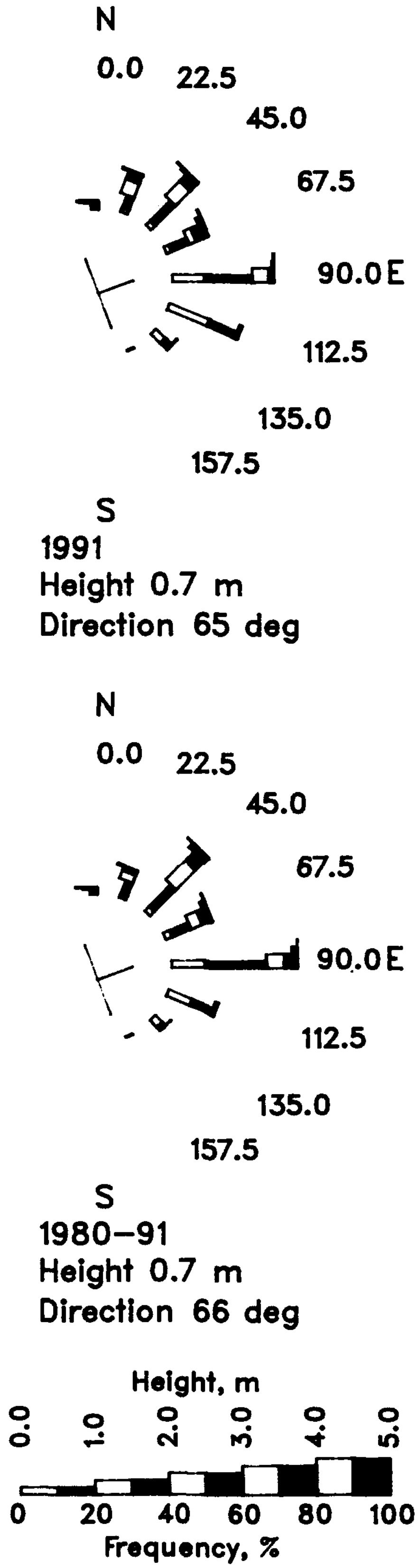


Figure 13. Annual wave roses

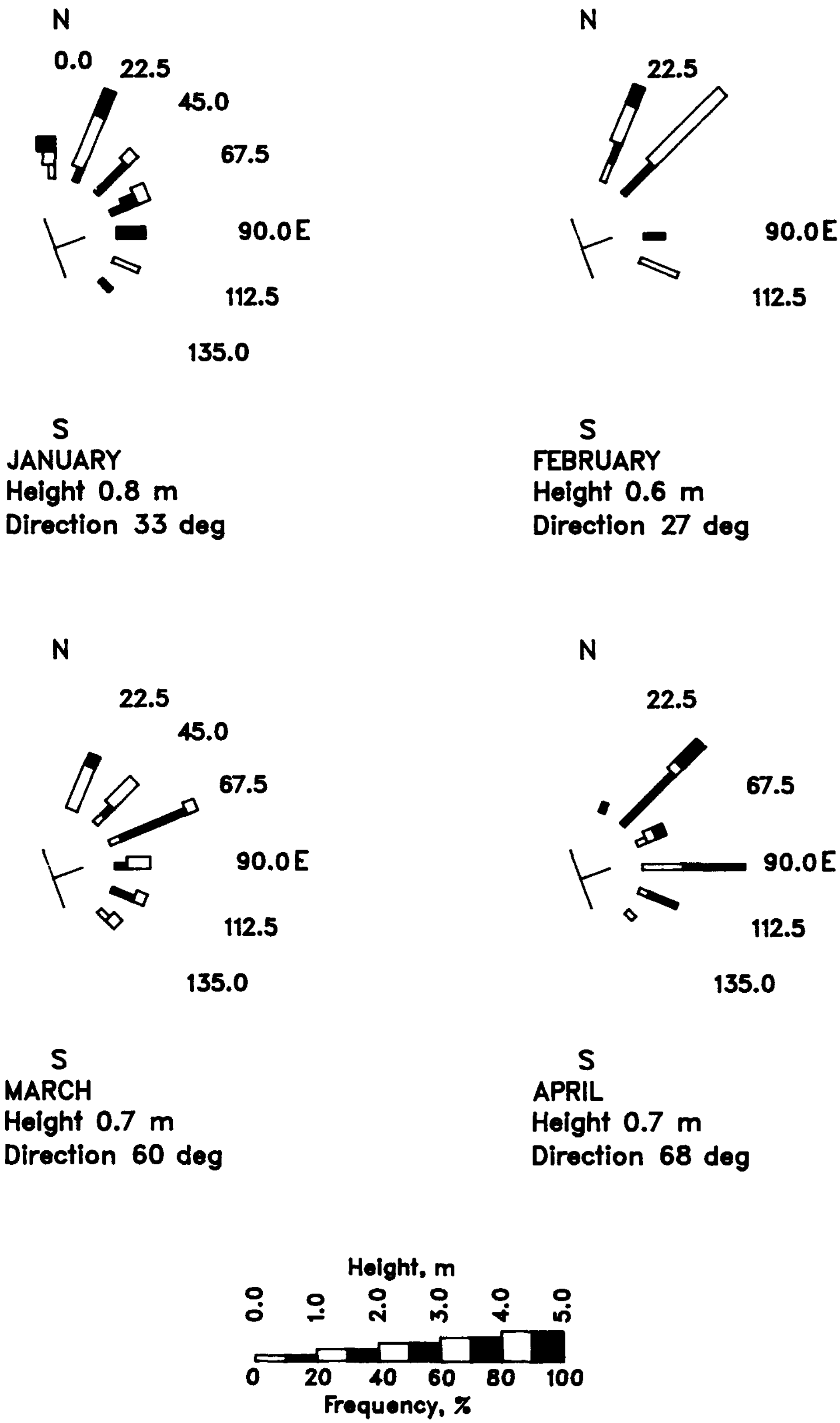


Figure 14. Monthly wave roses for 1991 (Sheet 1 of 3)

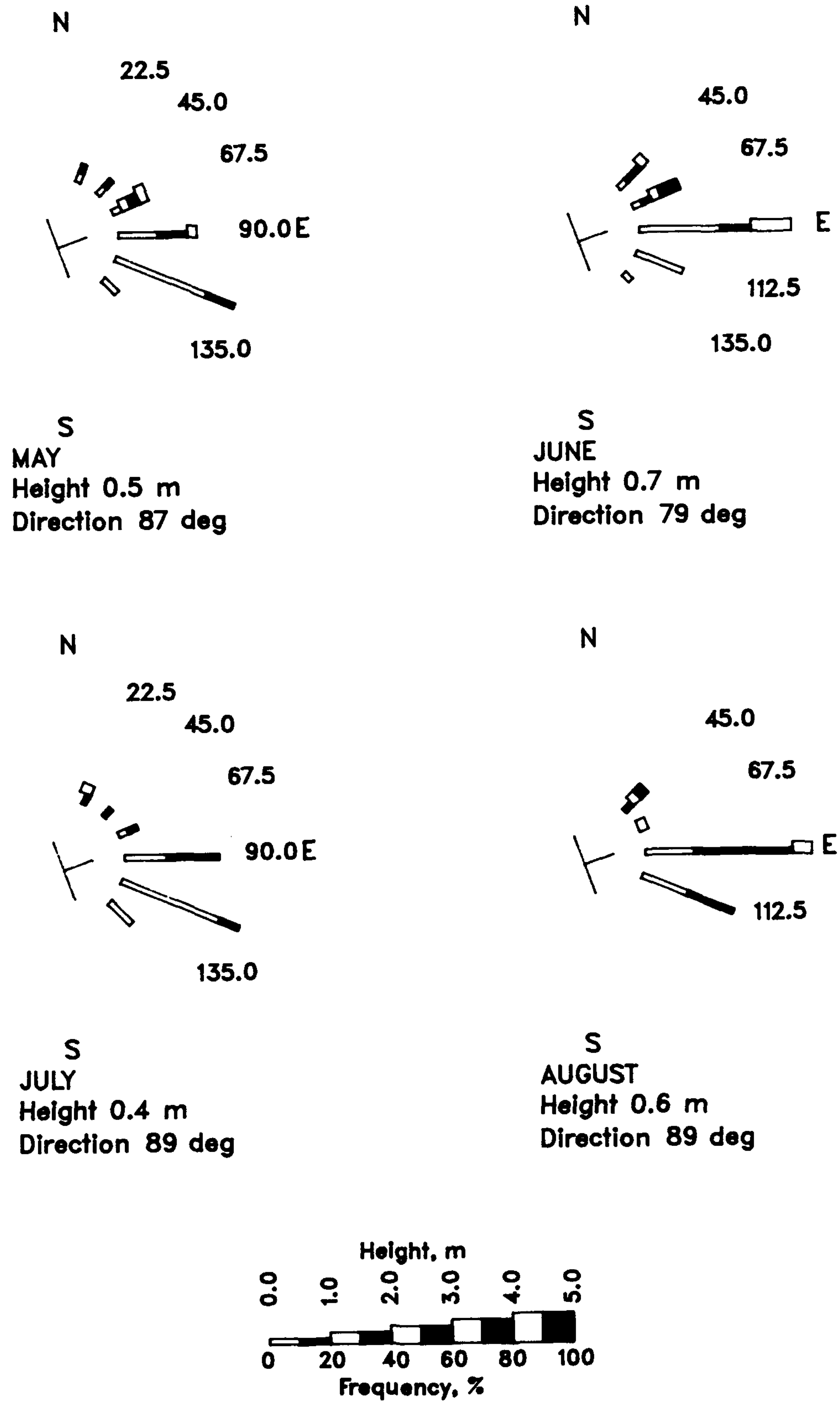


Figure 14. (Sheet 2 of 3)

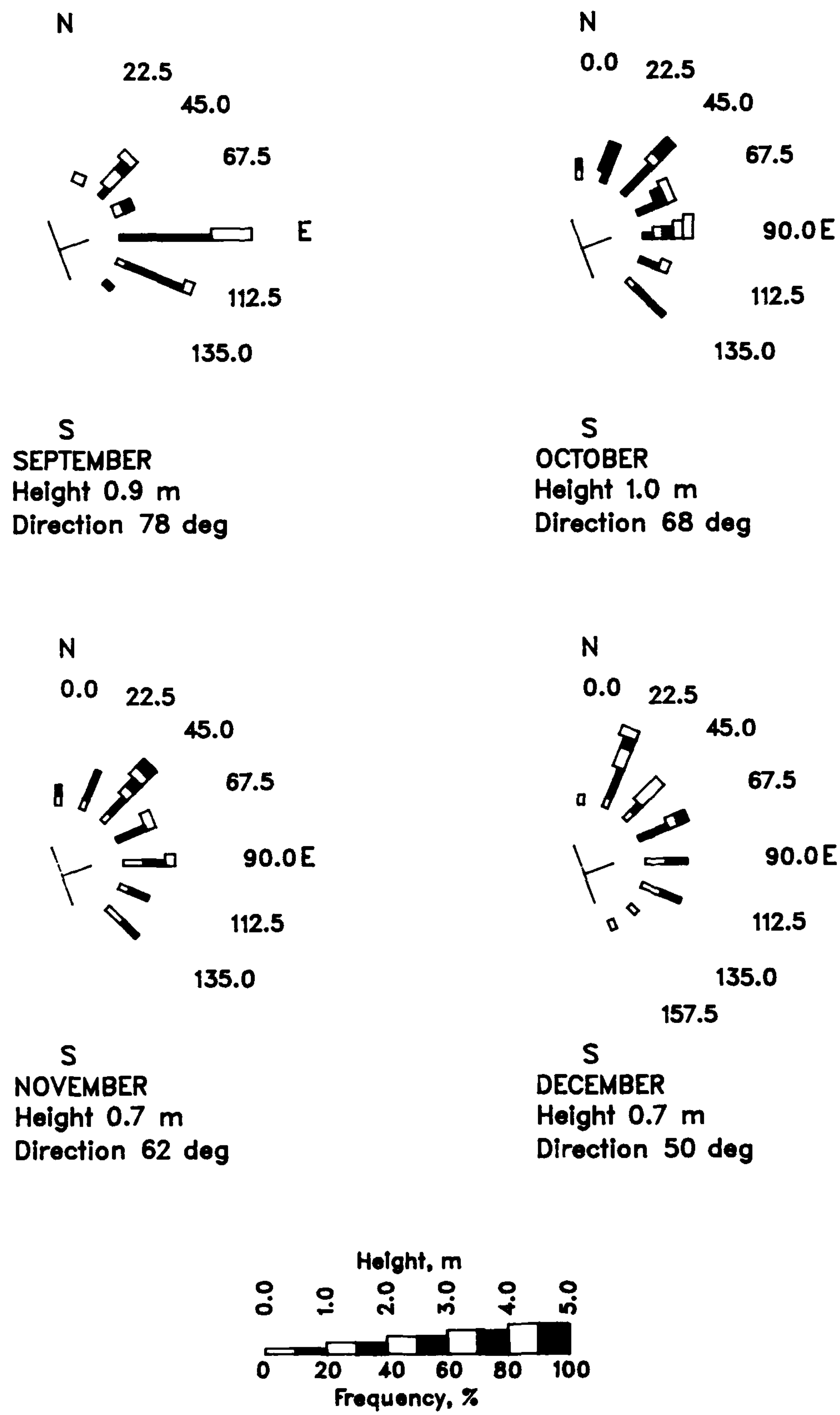


Figure 14. (Sheet 3 of 3)

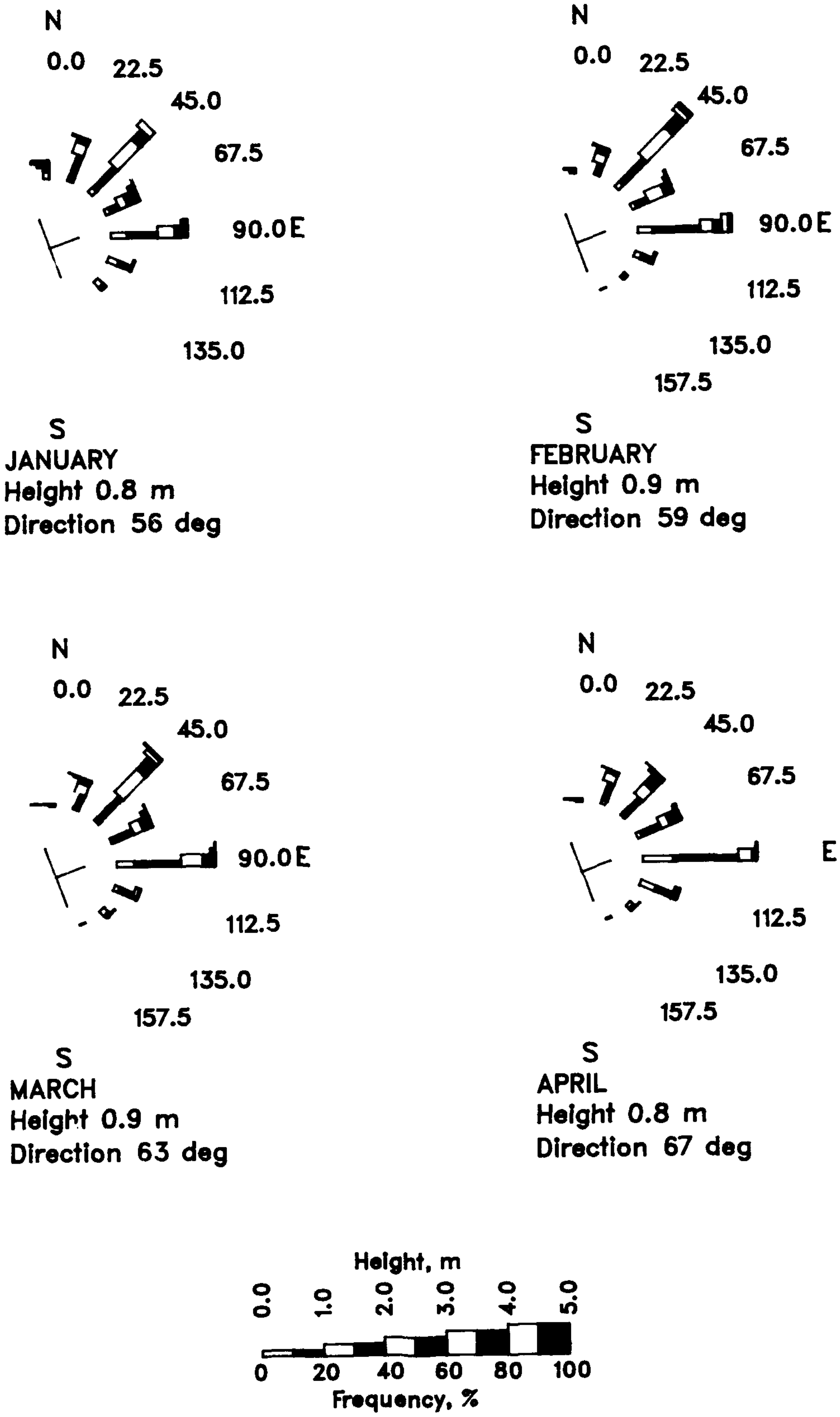
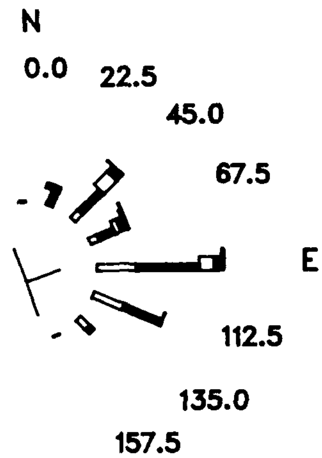
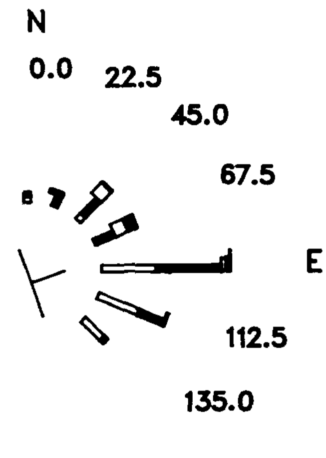


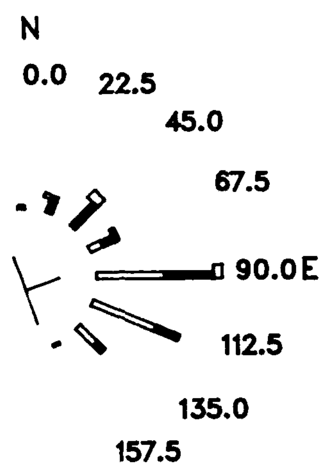
Figure 15. Monthly wave roses for 1980 through 1991
(Sheet 1 of 3)



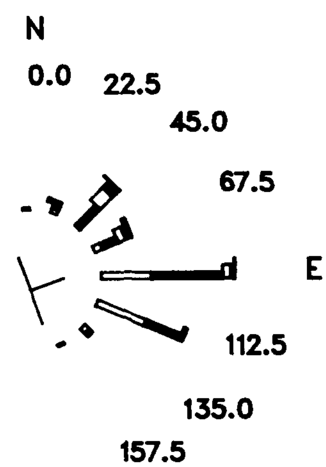
MAY
Height 0.6 m
Direction 74 deg



JUNE
Height 0.5 m
Direction 77 deg



JULY
Height 0.4 m
Direction 82 deg



AUGUST
Height 0.6 m
Direction 76 deg

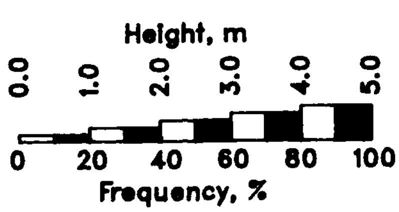


Figure 15. (Sheet 2 of 3)

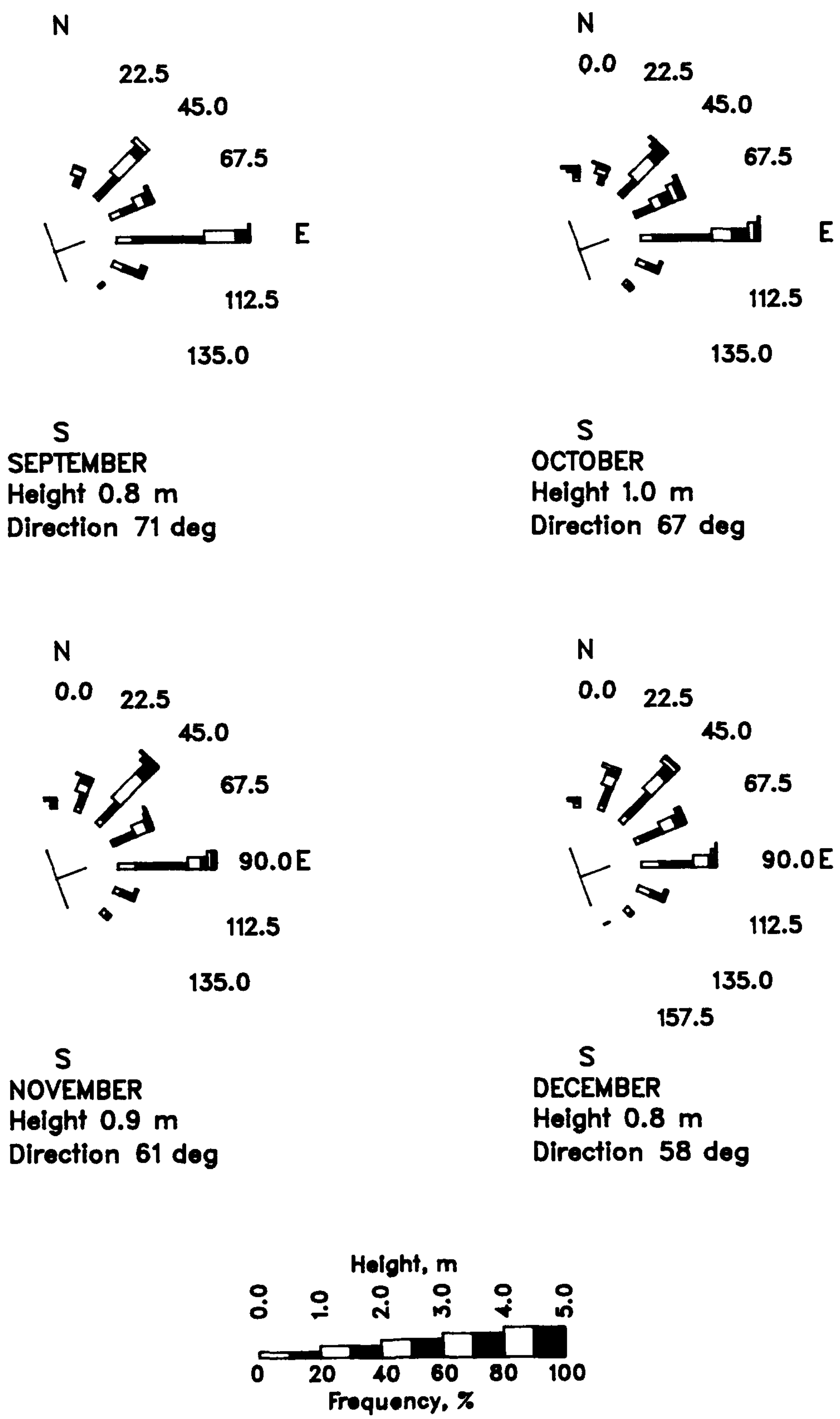


Figure 15 (Sheet 3 of 3)

PART IV: CURRENTS

44. Surface current speed and direction at the FRF are influenced by winds, waves, and, indirectly, by the bottom topography. The extent of the respective influences varies daily. However, winds tend to dominate the currents at the seaward end of the pier, whereas waves dominate within the surf zone.

Observations

45. Near 0700 EST, daily observations of surface current speed and direction were made at (a) the seaward end of the pier, (b) the midsurf position on the pier, and (c) 10 to 15 m from the beach 500 m updrift of the pier. Surface currents were determined by observing the movement of dye on the water surface.

Results

46. Annual mean and mean currents for 1980 through 1991 are presented in Table 6 and in Figure 16. Figure 16 shows the daily and average annual measurements at the beach, pier midsurf, and pier end locations. Since the relative influences of the winds and waves vary with position from shore, the current speeds and, to some extent, direction vary at the beach, midsurf, and pier end locations. Magnitudes generally are largest at the midsurf location and lowest at the end of the pier.

Table 6

Mean Longshore Surface Currents*

Month	Pier End, cm/sec 1991	Pier End, cm/sec 1980-1991	Pier Midsurf, cm/sec 1991	Pier Midsurf, cm/sec 1980-1991	Beach, cm/sec 1991	Beach, cm/sec 1980-1991
Jan	30	22	20	18	1	5
Feb	-6	5	1	5	5	8
Mar	11	14	5	8	3	8
Apr	15	13	23	12	-2	2
May	28	19	15	5	10	4
Jun	17	11	14	3	16	5
Jul	0	2	2	-7	-4	-8
Aug	20	15	7	-2	1	-2
Sep	7	7	11	1	-1	-2
Oct	-5	1	-7	-4	-10	-5
Nov	-3	5	-1	4	-4	4
Dec	11	13	9	13	-1	5
Annual	10	11	8	5	1	2

* + = southward; - = northward.

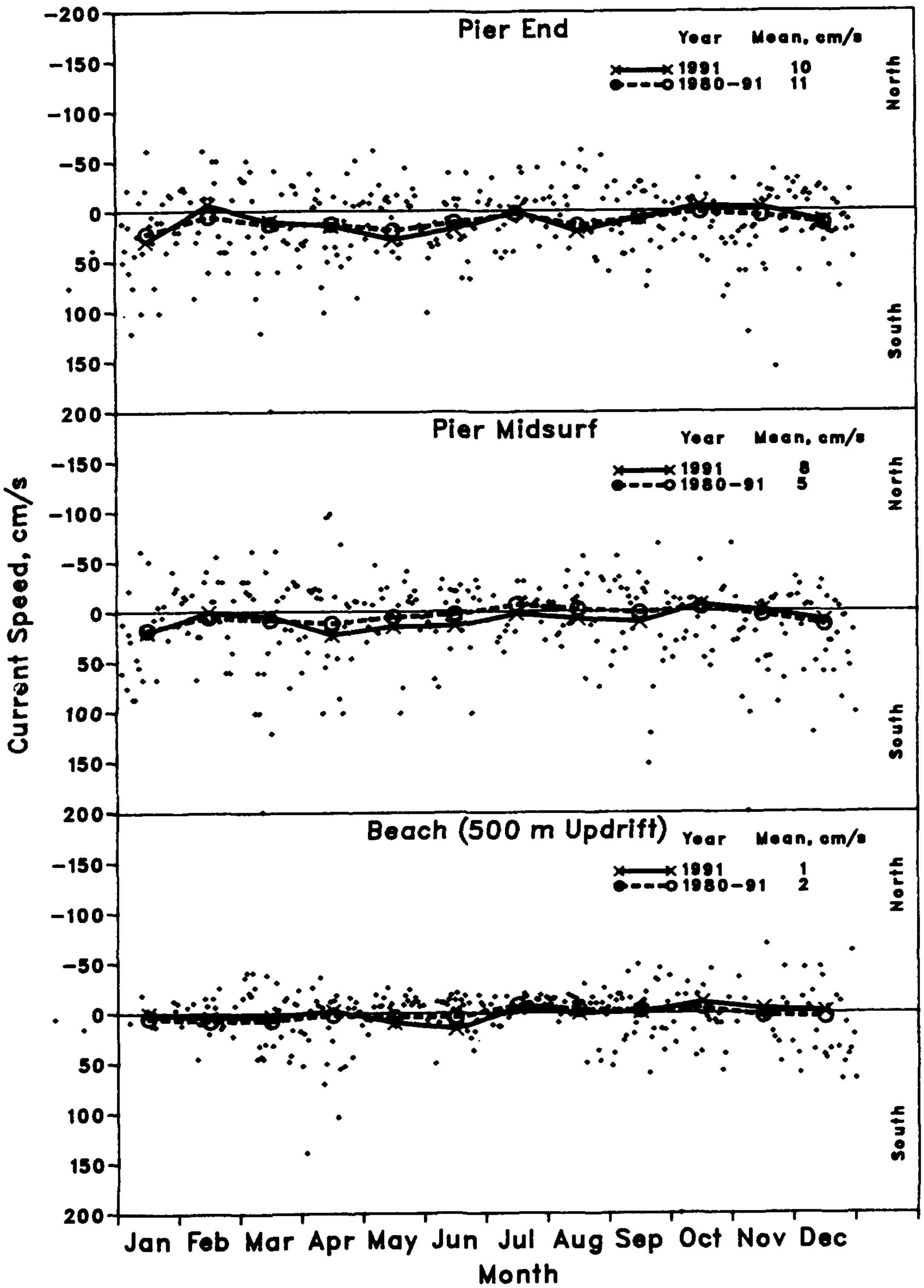


Figure 16. Daily current speeds and directions with monthly means for 1991

PART V: TIDES AND WATER LEVELS

Measurement Instrument

47. Water level data were obtained from an NOAA/NOS control tide station (sta 865-1370) located at the seaward end of the research pier (Figure 2) by using a Leupold and Stevens, Inc. (Beaverton, OR) digital tide gage. This analog-to-digital recorder is a float-activated, negator-spring, counterpoised instrument that mechanically converts the vertical motion of a float into a coded, punched paper tape record. The below-deck installation at pier sta 19+60 consisted of a 30.5-cm-diam stilling well with a 2.5-cm orifice and a 21.6-cm-diam float.

48. Operation and tending of the tide gage conformed to NOS standards. The gage was checked daily for proper operation of the punch mechanism and for accuracy of the time and water level information. The accuracy was determined by comparing the gage level reading with a level read from a reference electric tape gage. Once a week, a heavy metal rod was lowered down the stilling well and through the orifice to ensure free flow of water into the well. During the summer months, when biological growth was most severe, divers inspected and cleaned the orifice opening as required.

49. The tide station was inspected quarterly by an NOAA/NOS tide field group. Tide gage elevation was checked using existing NOS control positions, and the equipment was checked and adjusted as needed. Both NOS and FRF personnel also reviewed procedures for tending the gage and handling the data. Any specific comments on the previous months of data were discussed to ensure data accuracy.

50. Digital paper tape records of tide heights taken every 6 min were analyzed by the Tides Analysis Branch of NOS. An interpreter created a digital magnetic computer tape from the punch paper tape, which was then processed on a large computer. First, a listing of the instantaneous tidal height values was created for visual inspection. If errors were encountered, a computer program was used to fill in or recreate bad or missing data using correct values from the nearest NOS tide station and accounting for known time lags and elevation anomalies. The data were plotted, and a new listing was generated and rechecked. When the validity of the data had been confirmed, monthly tabulations of daily highs and lows, hourly heights (instantaneous

height selected on the hour), and various extreme and/or mean water level statistics were computed.

Results

51. Tides at the FRF are semidiurnal with both daily high and low tides approximately equal. Tide height statistics are presented in Table 7. Figure 17 plots the monthly tide statistics for all available data, and Figure 18 compares the distribution of daily high and low water levels and hourly tide heights. The monthly or annual mean sea level (MSL) reported is the average of the hourly heights, whereas the mean tide level is midway between mean high water (MHW) and mean low water (MLW), which are the averages of the daily high- and low-water levels, respectively, relative to NGVD. Mean range (MR) is the difference between MHW and MLW levels, and the lowest water level for the month is the extreme low (EL) water, while the highest water level is the extreme high (EH) water level.

Table 7

Tide Height Statistics*

Month or Year	Mean High Water	Mean Tide Level	Mean Sea Level	Mean Low Water	Mean Range	Extreme High	Date	Extreme Low	Date
					1991				
Jan	55	13	14	-28	83	87	2	-55	1
Feb	47	7	7	-33	80	85	26	-77	17
Mar	58	17	17	-24	82	88	30	-58	1
Apr	52	12	12	-28	80	101	21	-52	13
May	51	11	11	-29	80	92	18	-50	13
Jun	59	19	19	-22	81	106	23	-55	12
Jul	58	17	18	-23	81	88	11	-54	43
Aug	55	15	15	-26	81	82	25	-52	10
Sep	59	18	18	-23	82	95	1	-46	30
Oct	65	24	25	-16	81	125	31	-40	9
Nov	60	19	19	-21	81	118	1	-58	20
Dec	46	5	6	-35	81	96	24	-83	21
1991	55	15	15	-26	81	125	Oct	-83	Dec
					Prior Years				
1990	49	9	9	-32	81	109	May	-78	Feb
1989	49	9	9	-31	80	199	Mar	-77	Apr
1988	46	6	7	-33	79	129	Apr	-72	Dec
1987	55	15	16	-24	79	113	Jan	-63	Nov
1986	60	13	13	-35	95	123	Dec	-108	Jan
1985	59	10	11	-37	96	136	Dec	-93	Apr
1984	64	16	16	-32	97	147	Oct	-77	Jul
1983	68	19	19	-30	98	143	Jan	-73	Mar
1982	58	8	9	-42	99	127	Oct	-108	Feb
1981	59	8	9	-42	101	149	Nov	-110	Apr
1980	59	8	8	-43	102	118	Mar	-119	Mar
1979	60	9	9	-43	103	121	Feb	-95	Sep
1979-1991	57	11	11	-35	93	199	Mar 1989	-119	Mar 1980

* Measurements are in centimeters.

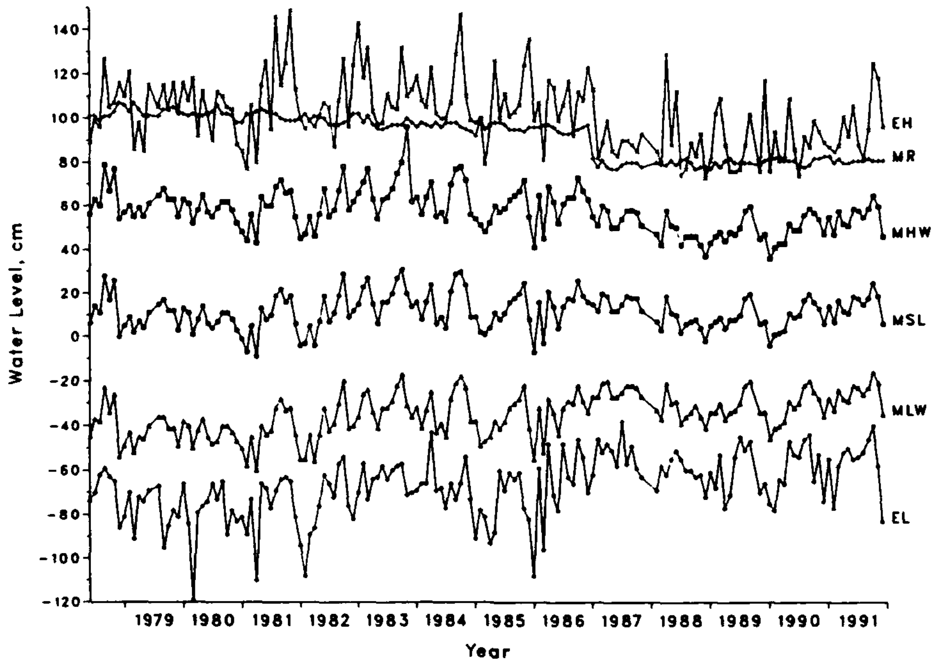


Figure 17. Monthly tide and water level statistics relative to NGVD

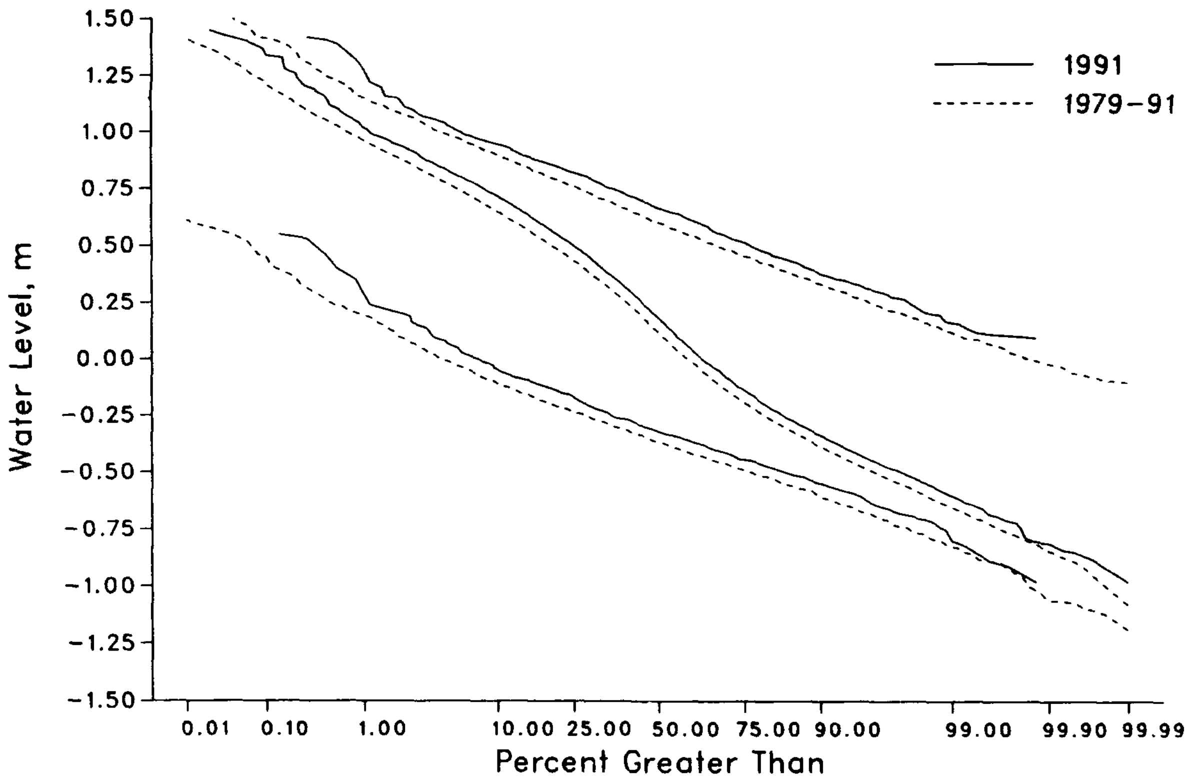


Figure 18. Distributions of hourly tide heights and high- and low-water levels

PART VI: WATER CHARACTERISTICS

52. Monthly averages of daily measurements of surface water temperature, visibility, and density at the seaward end of the FRF pier are given in Table 8. The summaries represent single observations made near 0700 EST and, therefore, may not reflect daily average conditions since such characteristics can change within a 24-hr period. Large temperature variations were common when there were large differences between the air and water temperatures and variations in wind direction. From past experience, persistent onshore winds move warmer surface water toward the shoreline, although offshore winds cause colder bottom water to circulate shoreward, resulting in lower temperatures.

Table 8

Mean Surface Water Characteristics

	Temperature deg C		Visibility m		Density g/cm^3	
Month	1991	1980-1991	1991	1980-1991	1991	1980-1991
Jan	8.9	6.1	1.6	1.3	1.0223	1.0234
Feb	9.1	5.6	2.2	1.8	1.0228	1.0232
Mar	10.1	7.1	1.7	1.6	1.0225	1.0229
Apr	12.5	11.1	2.5	2.3	1.0219	1.0225
May	17.6	15.5	2.5	2.4	1.0211	1.0221
Jun	22.4	19.6	2.6	3.4	1.0202	1.0214
Jul	23.6	22.1	4.8	3.8	1.0213	1.0214
Aug	25.1	23.9	2.7	3.2	1.0206	1.0204
Sep	23.9	23.1	2.7	2.3	1.0212	1.0209
Oct	20.2	19.5	1.8	1.6	1.0218	1.0217
Nov	13.9	14.8	1.2	1.1	1.0237	1.0229
Dec	11.7	10.1	1.3	1.1	1.0248	1.0235
Annual	16.6	14.9	2.3	2.1	1.0220	1.0222

Temperature

53. Daily sea surface water temperatures (Figure 19) were measured with an NOS water sampler and thermometer. Monthly mean water temperatures (Table 8) varied with the air temperatures (see Table 2).

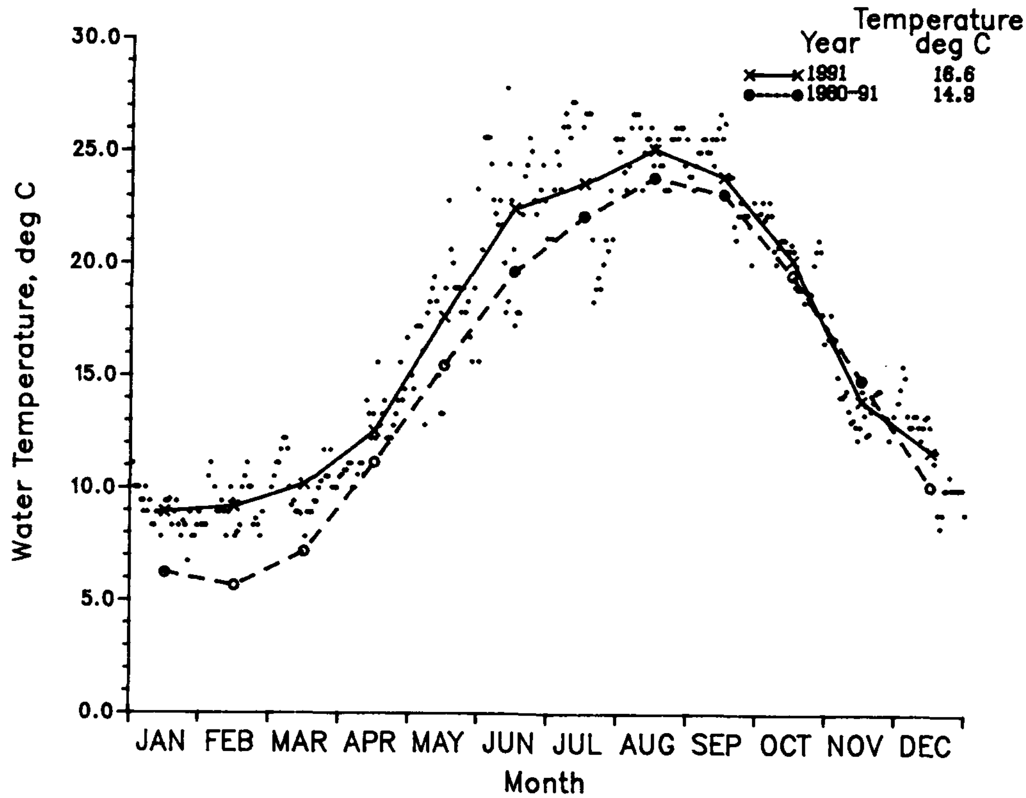


Figure 19. Daily water temperature values with monthly means

Visibility

54. Visibility in coastal nearshore waters depends on the amount of salts, soluble organic material, detritus, living organisms, and inorganic particles in the water. These dissolved and suspended materials change the absorption and attenuation characteristics of the water that vary daily and yearly.

55. Visibility was measured with a 0.3-m-diam Secchi disk, and similar to water temperature, variation was related to onshore and offshore winds. Onshore winds moved warm clear surface water toward shore, whereas offshore winds brought up colder bottom water with large concentrations of suspended matter. Figure 20 presents the daily and monthly mean surface visibility values for the year. Large variations were common, and visibility less than 1 m was expected in any month. Monthly means are given in Table 8.

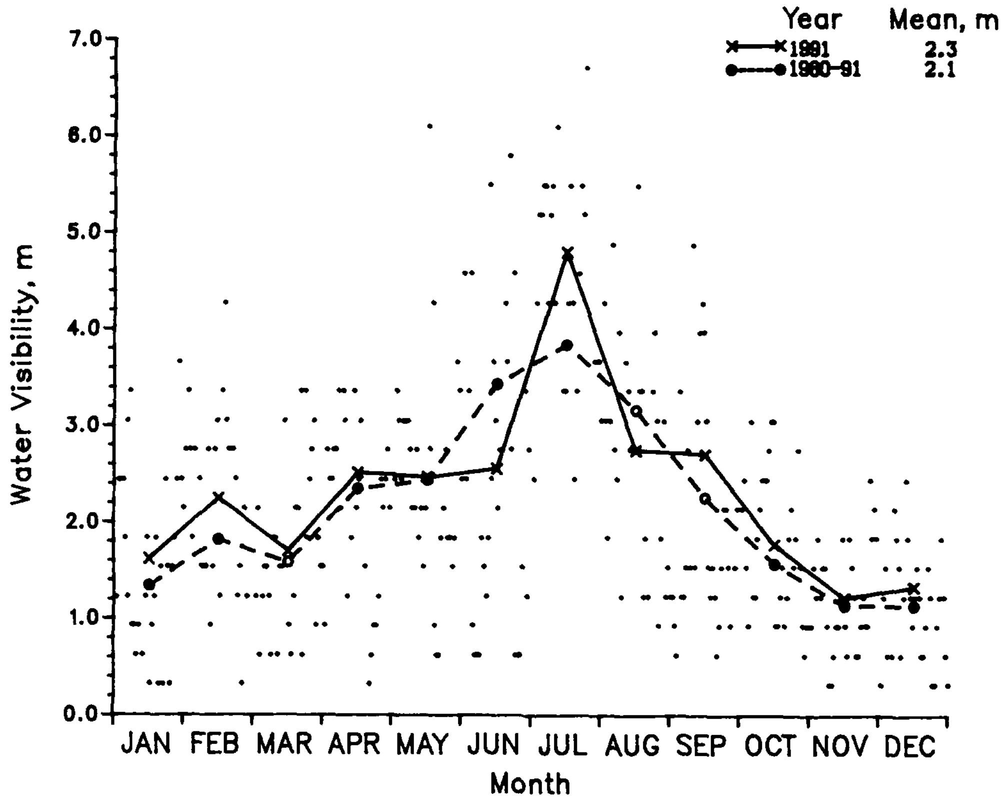


Figure 20. Daily water visibility values with monthly means

Density

56. Daily and monthly mean surface density values, plotted in Figure 21, were measured with a hydrometer. Monthly means are also given in Table 8.

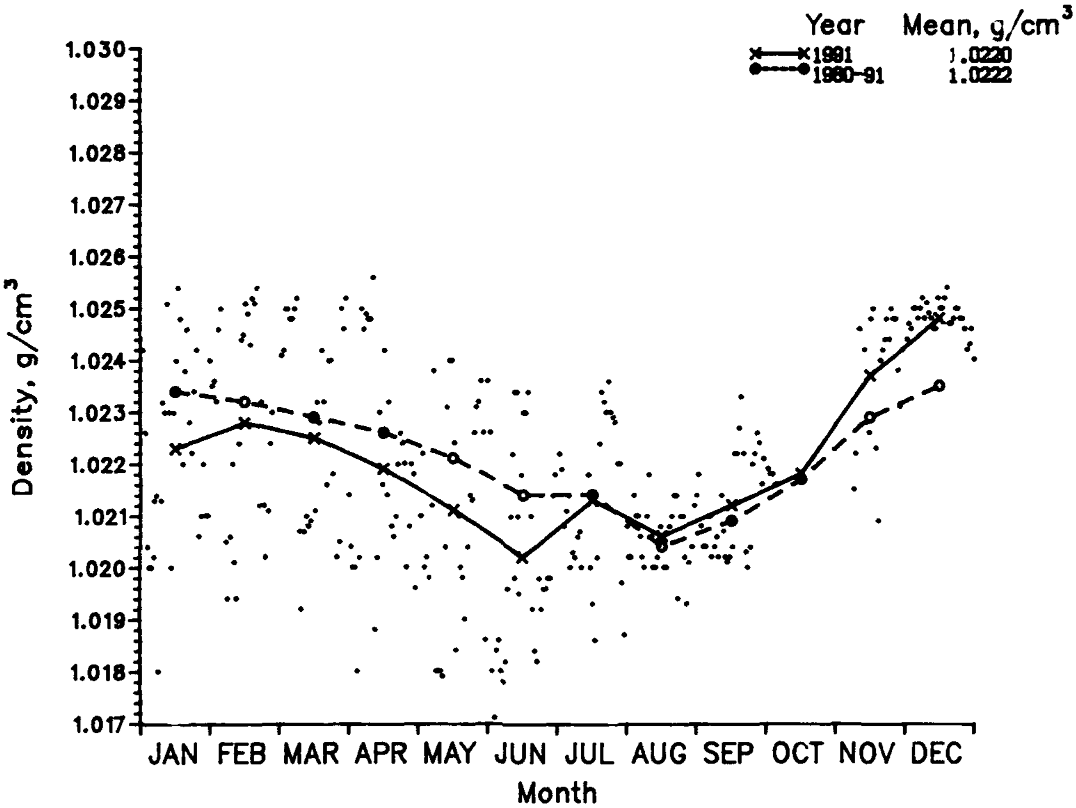


Figure 21. Daily water density values with monthly means

PART VII: SURVEYS

57. Waves and currents interacting with bottom sediments produce changes in the beach and nearshore bathymetry. These changes can occur very rapidly in response to storms, or slowly as a result of persistent but less forceful seasonal variations in wave and current conditions.

58. Nearshore bathymetry at the FRF is characterized by regular shore-parallel contours, a moderate slope, and a barred surf zone (usually an outer storm bar in water depths of about 4.5 m and an inner bar in water depths between 1.0 and 2.0 m). This pattern is interrupted in the immediate vicinity of the pier where a permanent trough runs under much of the pier, ending in a scour hole where depths can be up to 3.0 m greater than the adjacent bottom (Figure 22). This trough, which apparently is the result of the interaction of waves and currents with the pilings, varies in shape and depth with changing wave and current conditions. The effect of the pier on shore-parallel contours occurs as far as 300 m away, and the shoreline may be affected up to 350 m from the pier (Miller, Birkemeier, and DeWall 1983).

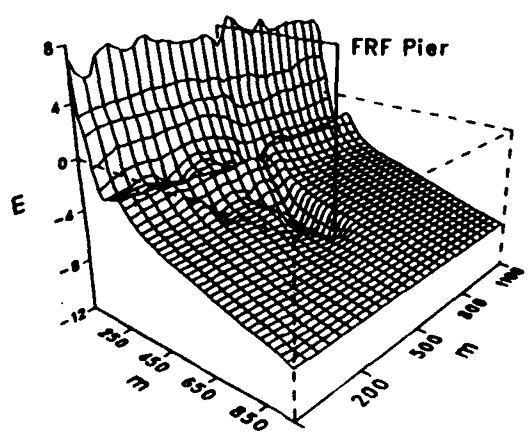


Figure 22. Permanent trough under the FRF pier, 23 September 1991

59. Approximately once a month, surveys were conducted of an area extending 600 m north and south of the pier and approximately 950 m offshore. This was done in order to document the temporal and spatial variability in bathymetry. Contour maps resulting from these surveys, along with plots of change in elevation between surveys, are given in Appendix A.

60. All surveys used the Coastal Research Amphibious Buggy (CRAB), a 10.7-m-tall amphibious tripod described by Birkemeier and Mason (1984), and a Geodimeter electronic surveying system, a Geodimeter 140-T self-tracking, electronic theodolite, distance meter. The profile locations are shown in each figure in Appendix A. Monthly soundings along both sides of the FRF pier were collected by lowering a weighted measuring tape to the bottom and recording the distance below the pier deck. Soundings were taken midway between the pier pilings to minimize errors caused by scour near the pilings.

61. A history of bottom elevations below Gages 645 and 625 is presented in Figure 23 for pier stations 7+80 (238 m) and 18+60 (567 m), along with intermediate locations, 323 and 433 m.

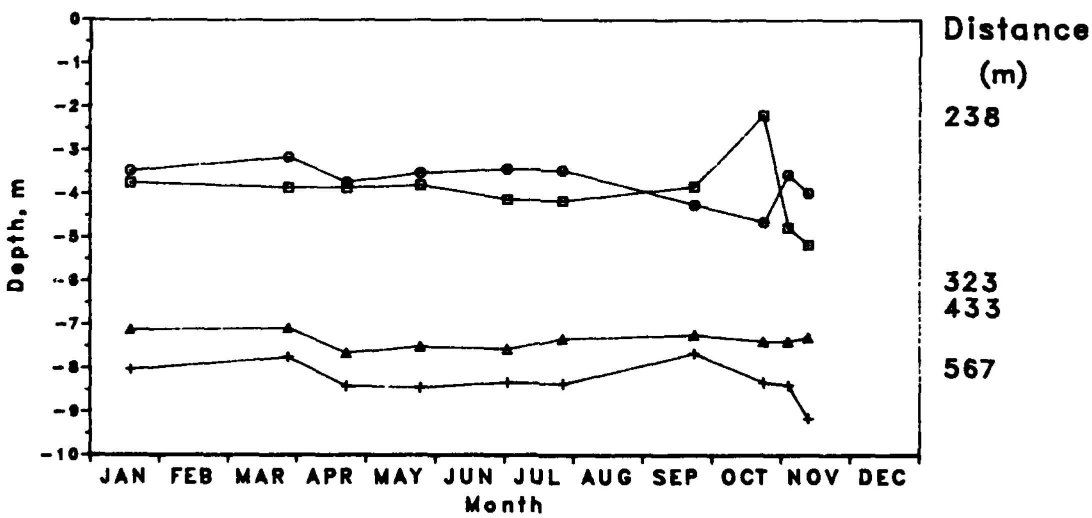


Figure 23. Time history of bottom elevations at selected locations under the FRF pier

PART VIII: PHOTOGRAPHY

Aerial Photographs

62. Aerial photographs were taken biannually using a 23-cm aerial mapping camera at a scale of 1:12,000. All coverage was at least 60-percent overlap, with flights flown as closely as possible to low tide between 1000 and 1400 EST with less than 10-percent cloud cover. The flight lines covered are shown in Figure 24. Figure 25 is a sample of the imagery obtained on 23 January 1990; the available aerial photographs for the year are:

Date	Flight Lines	Format
14 Jan	1	B/W
	2	Color

Beach Photographs

63. Daily color slides of the beach were taken using a 35-mm camera from the same location on the pier looking north and south (Figure 26). The location from which each picture was taken, as well as the date, time, and a brief description of the picture, were marked on each of the slides.

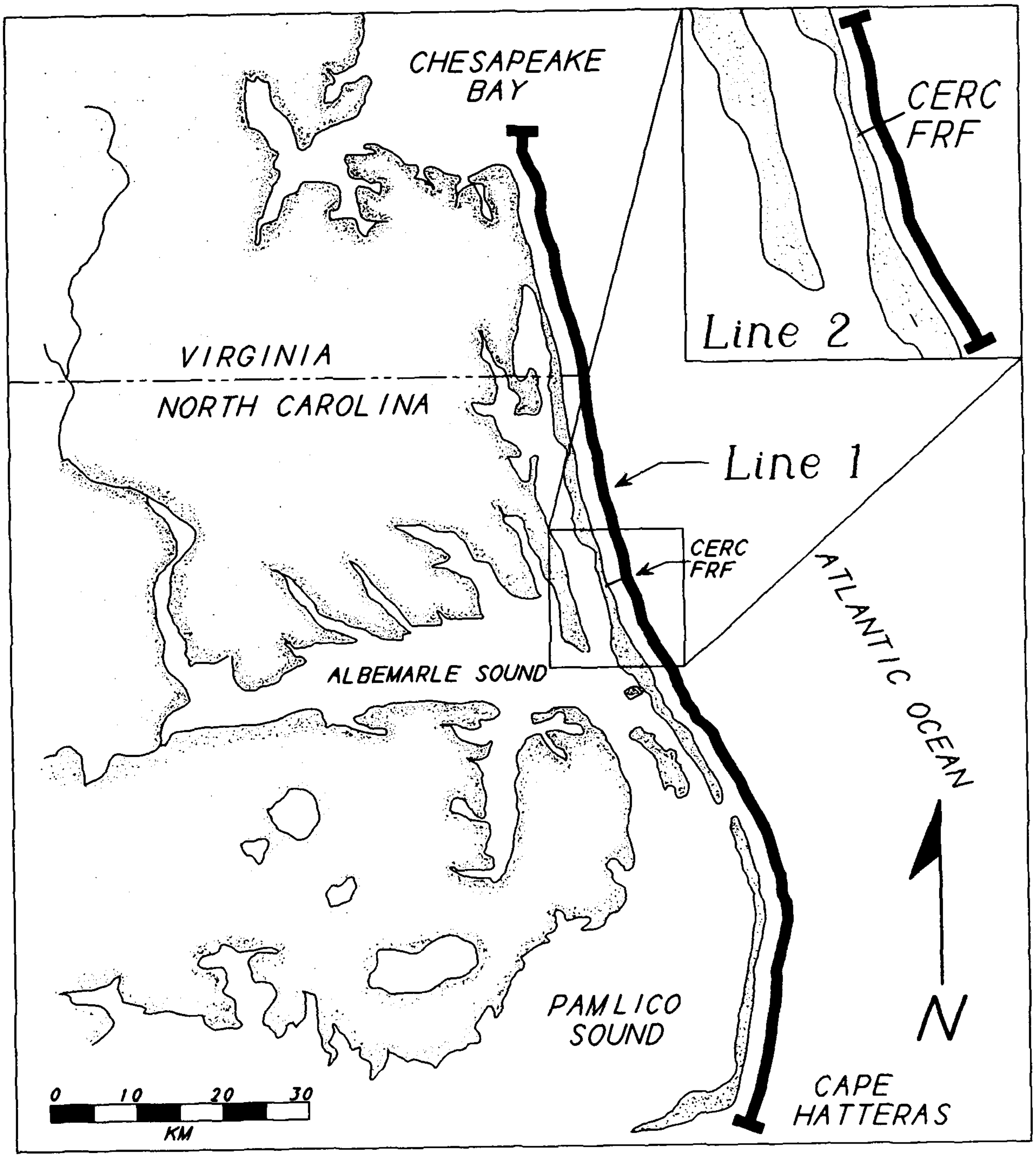
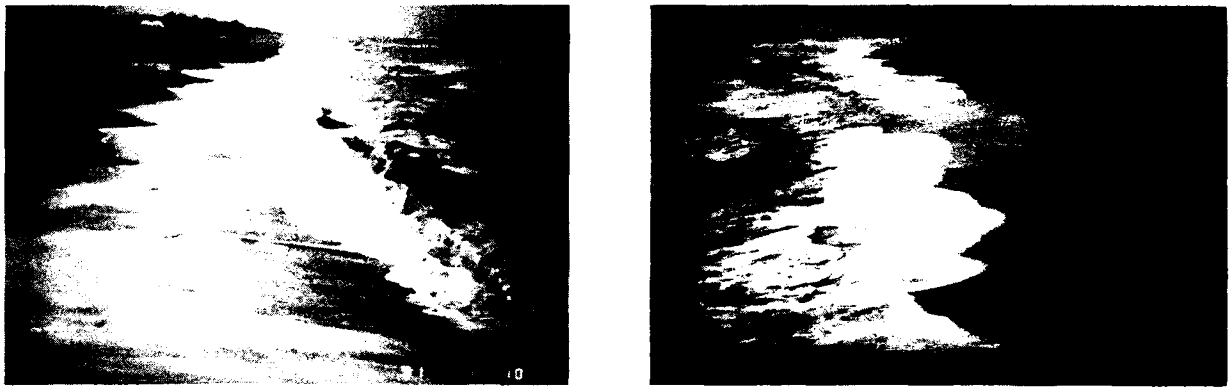


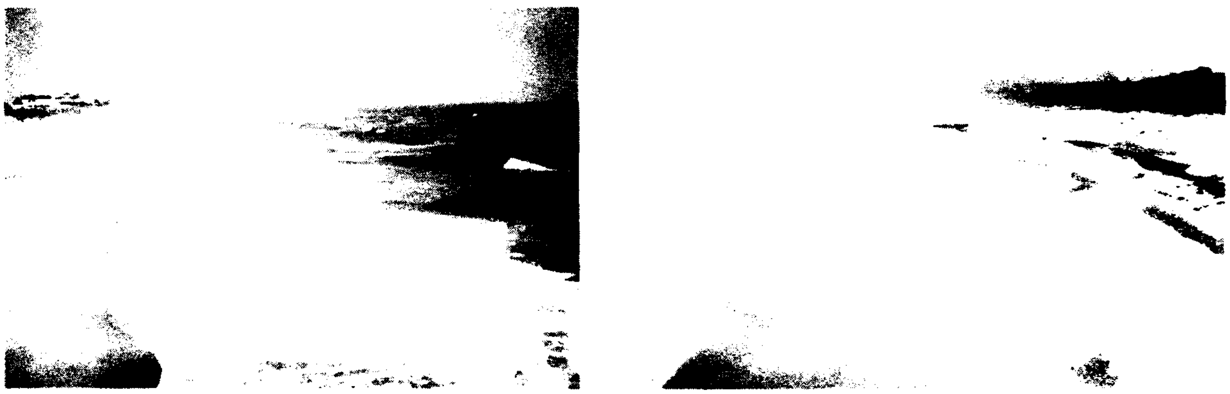
Figure 24. Aerial photography flight lines

Figure 25. Sample aerial photograph, 23 January 1990
(Scale = 1:12,000)

North View South View



a. 10 January 1991

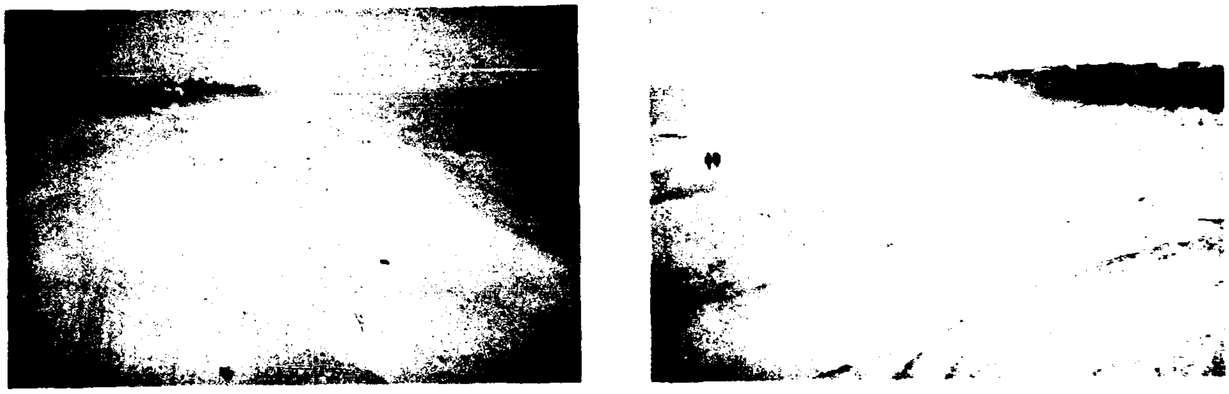


b. 10 February 1991

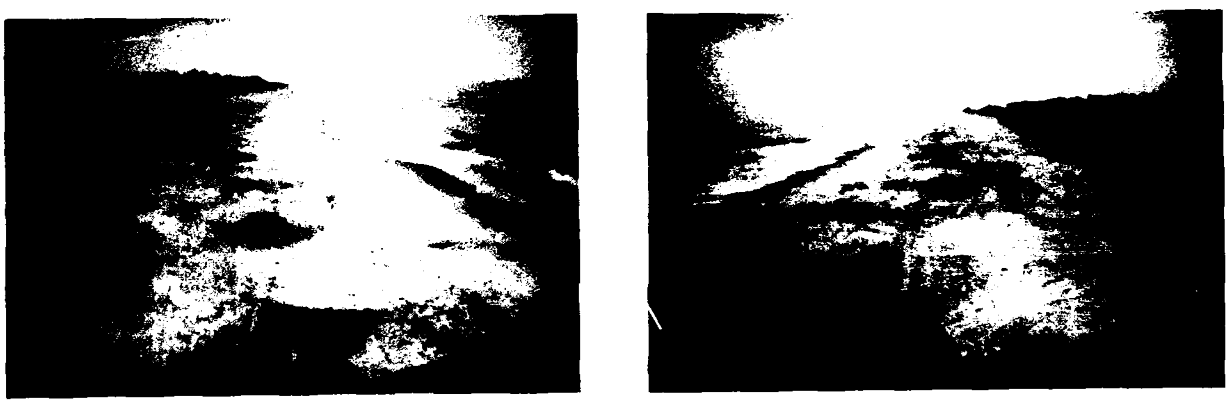
c. 10 March 1991

Figure 26. Beach photos looking north and south from the FRF pier (Sheet 1 of 4)

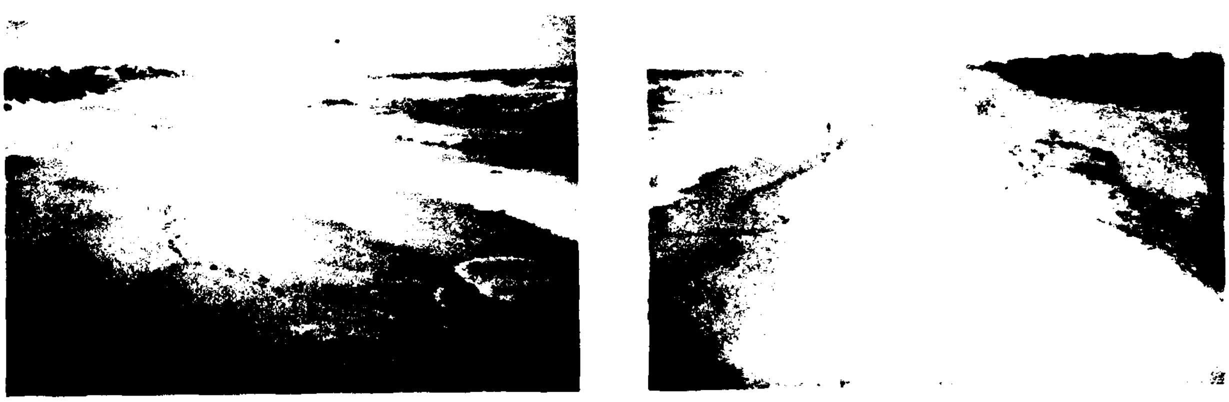
North View South View



d. 10 April 1991



e. 10 May 1991

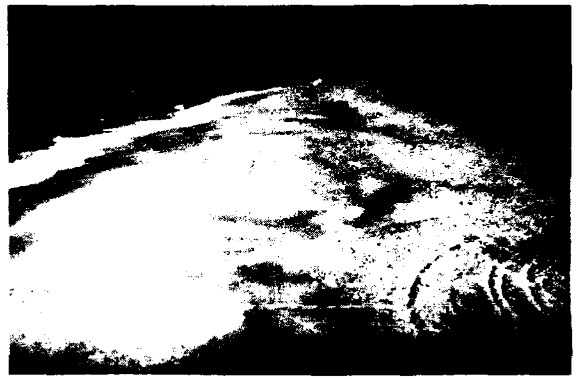


f. 5 June 1991

Figure 26. (Sheet 2 of 4)

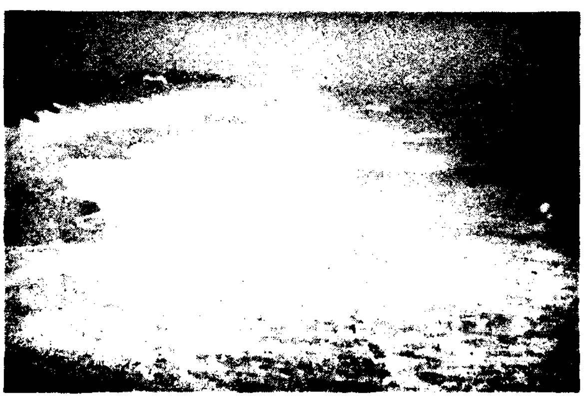
North View

South View



g. 10 July 1991

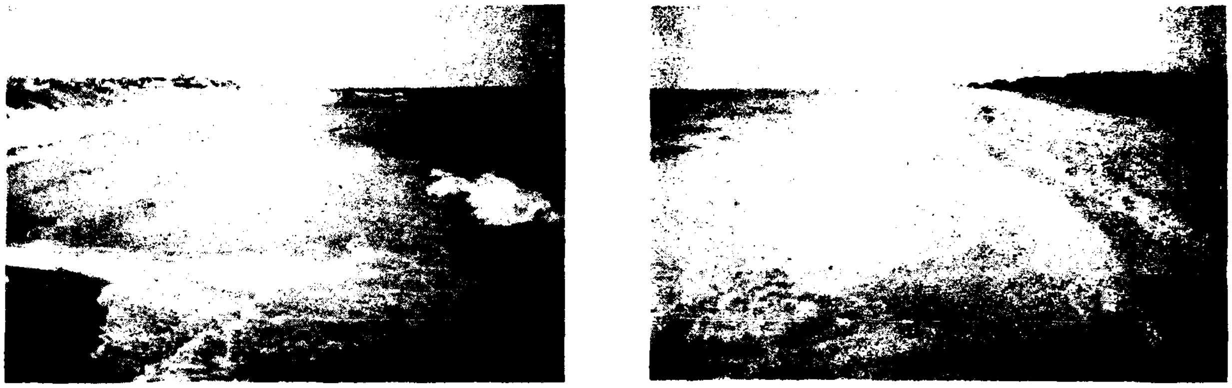
h. 10 August 1991



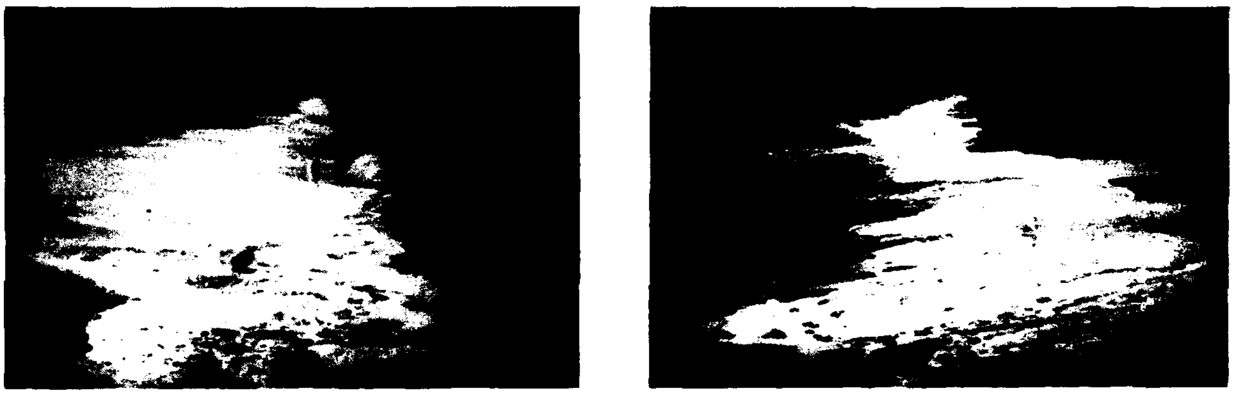
i. 10 September 1991

Figure 26. (Sheet 3 of 4)

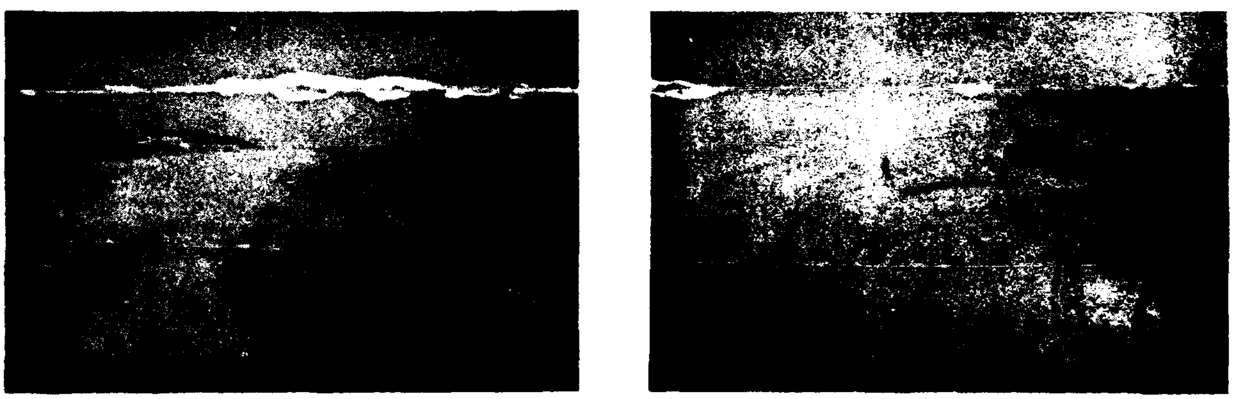
North View South View



j. 10 October 1991



k. 11 November 1991



l. 8 December 1991

Figure 26. (Sheet 4 of 4)

PART IX: STORMS

64. This section discusses storms (defined here as times when the wave height parameter, H_{mo} , equaled or exceeded 2 m at the seaward end of the FRF pier). Sample spectra from Gage 630 are given in Appendix B. Prestorm and/or poststorm bathymetry diagrams are given in Appendix A. Tracking information was provided by NOAA Daily Weather Maps (US Department of Commerce 1991).

7-9 January 1991 (Figure 27)

65. Winds from a strong Canadian high-pressure system began to generate storm waves at the FRF late on 7 January. Development of a weak coastal storm off the Georgia coast early on 8 January prolonged the period of onshore winds. The maximum H_{mo} (at Gage 625) of 2.96 m (T_p = 10.67 sec) was attained at 2342 EST on 8 January. Maximum winds (from the northeast) approaching 15 m/s occurred at 2042 EST on 7 January.

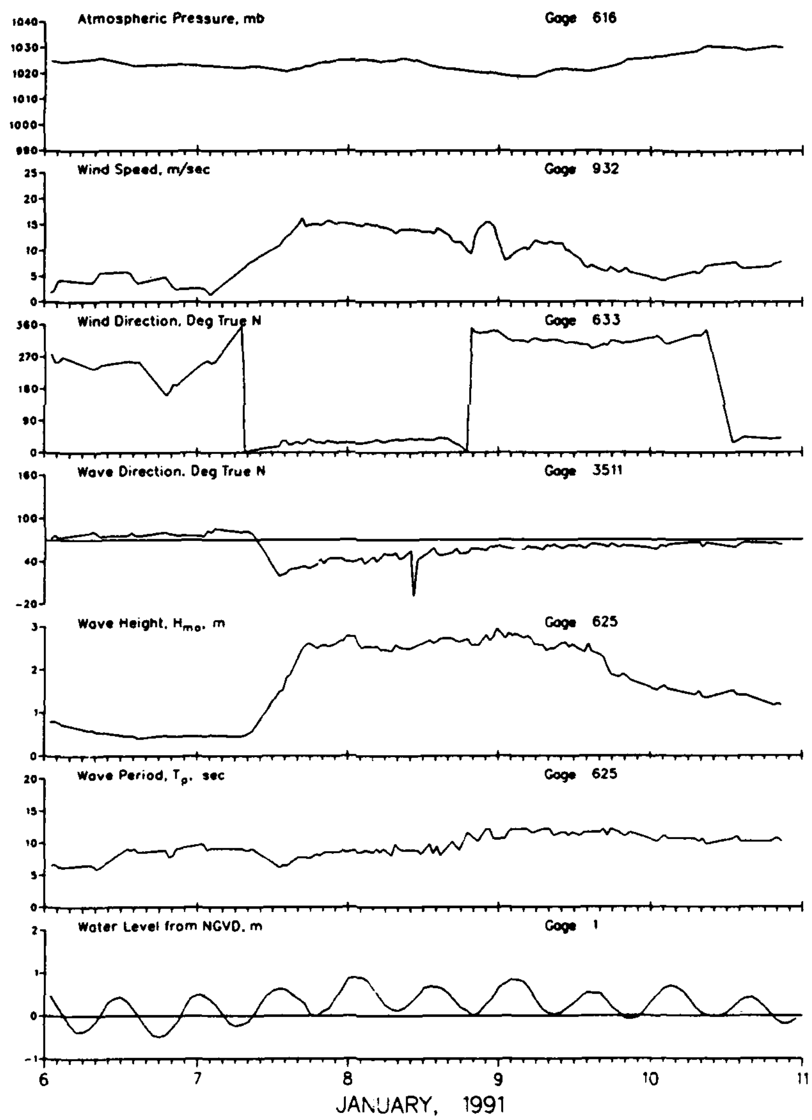


Figure 27. Data for 7-9 January 1991 storm

11-12 January 1991 (Figure 28)

66. Following directly behind the storm on 8 January, another Canadian high-pressure system briefly regenerated storm waves at the FRF. Maximum winds (from the southeast) exceeding 13 m/s peaked at 2042 EST on 11 January with the maximum H_{mo} (at Gage 625) of 2.25 m (T_p = 8.83 sec) occurring early the next day at 0100 EST.

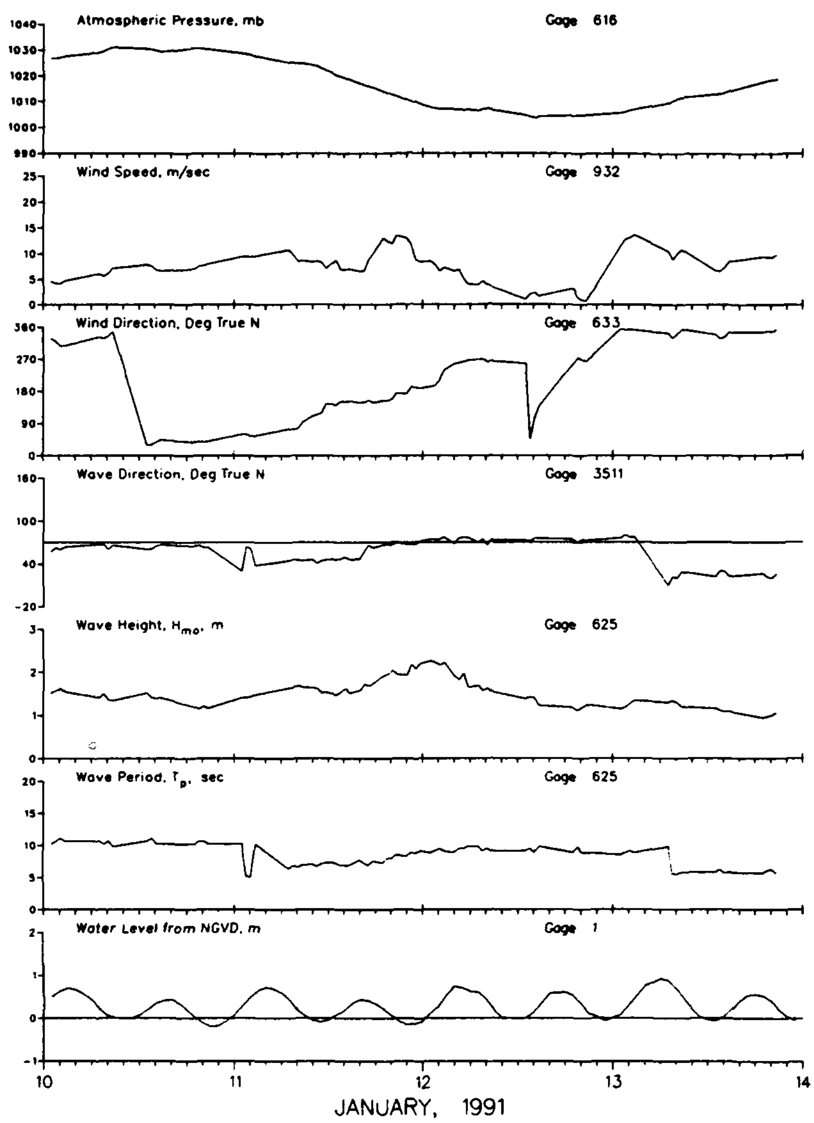


Figure 28. Data for 11-12 January 1991 storm

23 February 1991 (Figure 29)

67. Developing in the Gulf of Mexico off Texas on 20 February, this weak storm slowly moved across the southern U.S., being located over South Carolina on 23 February and moving offshore the following day. Peak winds (from the north-northeast) approached 16 m/s at 0508 EST on 23 February. The maximum H_{mo} (at Gage 625), which was recorded later that day at 1900 EST, reached 2.30 m (T_p = 7.53 sec). The minimum atmospheric pressure of 1,003.4 mb occurred at 1708 EST on 22 February. There was no precipitation at the FRF from this storm.

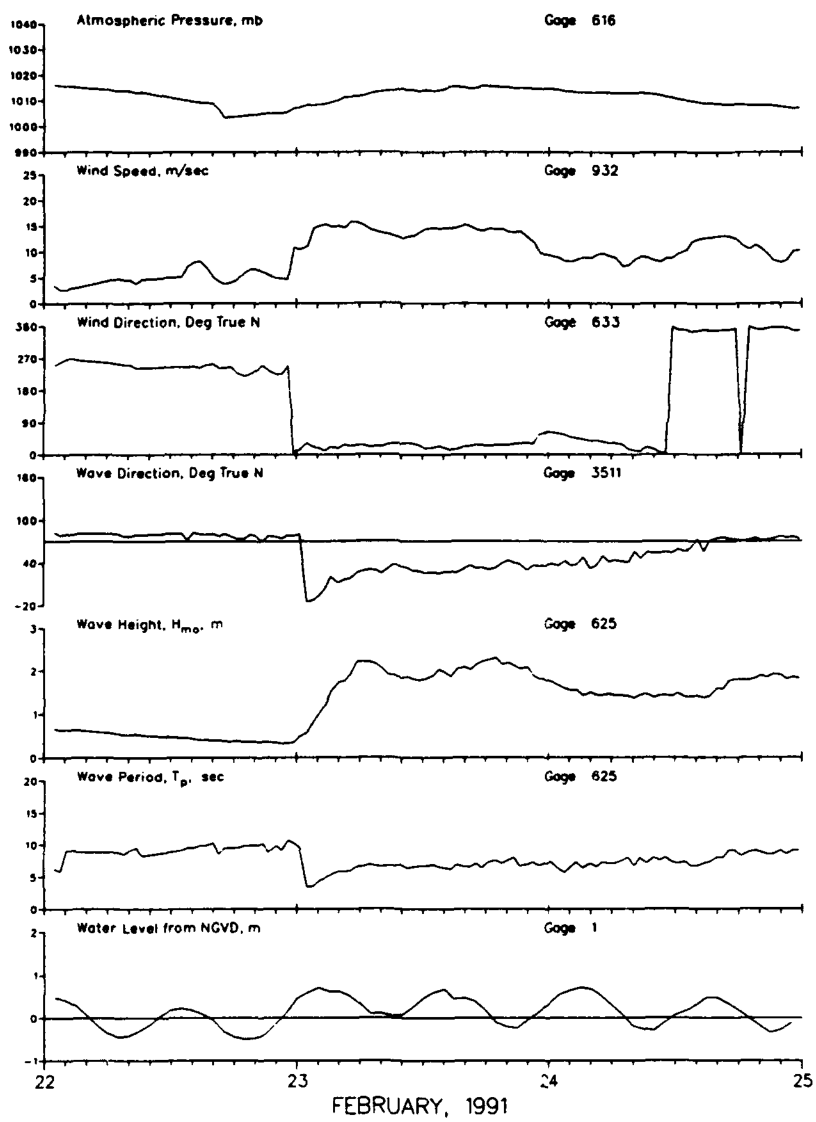


Figure 29. Data for 23 February 1991 storm

<u>6-7 March 1991 (Figure 30)</u>

68. Winds from a strong Canadian high-pressure system began to generate storm waves at the FRF late on 6 March. The maximum H_{mo} (at Gage 625) of 2.50 m (T_p = 7.53 sec) was attained at 0208 EST on 7 March. Maximum winds (from the northeast) exceeding 16 m/s occurred at 0542 EST also on 7 March.

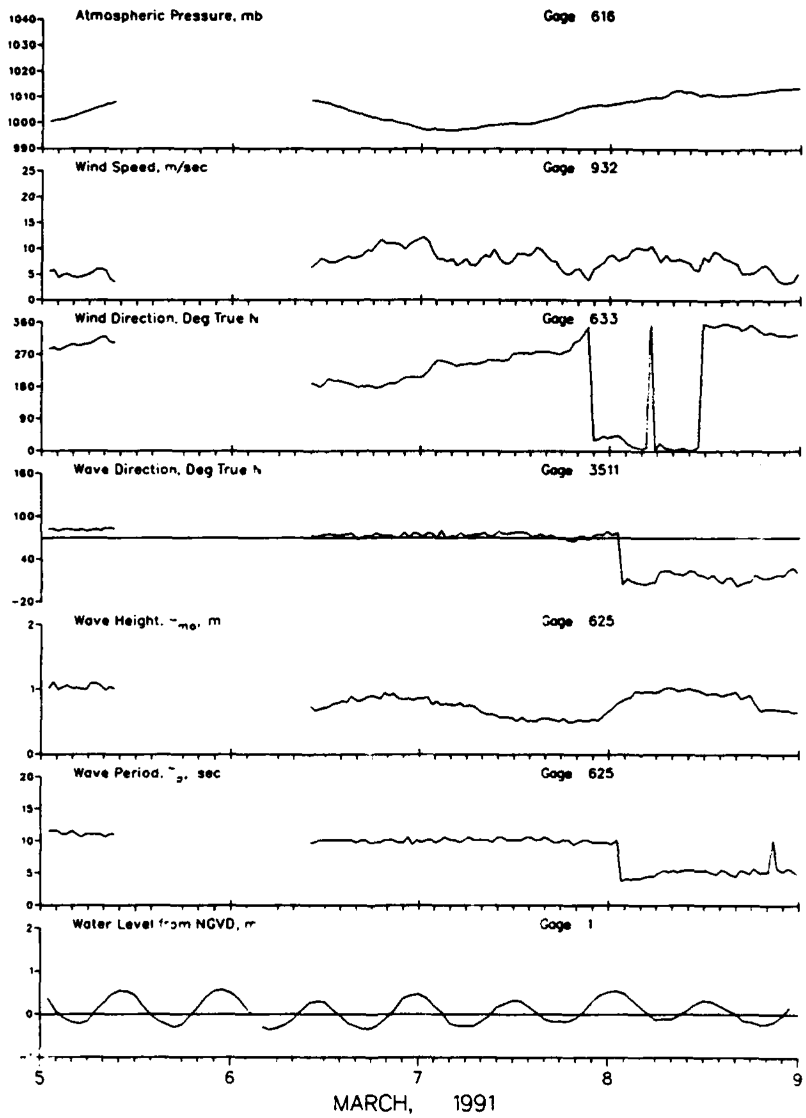


Figure 30. Data for 6-7 March 1991 storm

29 March 1991 (Figure 31)

69. Developing over South Carolina on 29 March, this storm rapidly moved to the northeast, being located off the Virginia coast by 30 March. Maximum winds approaching 16 m/s peaked at 1634 EST on 29 March with the maximum H_{mo} (at Gage 625) of 2.22 m (T_p = 6.92 sec) occurring later the same day at 1934 EST. The minimum atmospheric pressure of 1,014.0 mb was recorded at 0400 EST on 30 March. Total precipitation was 30 mm.

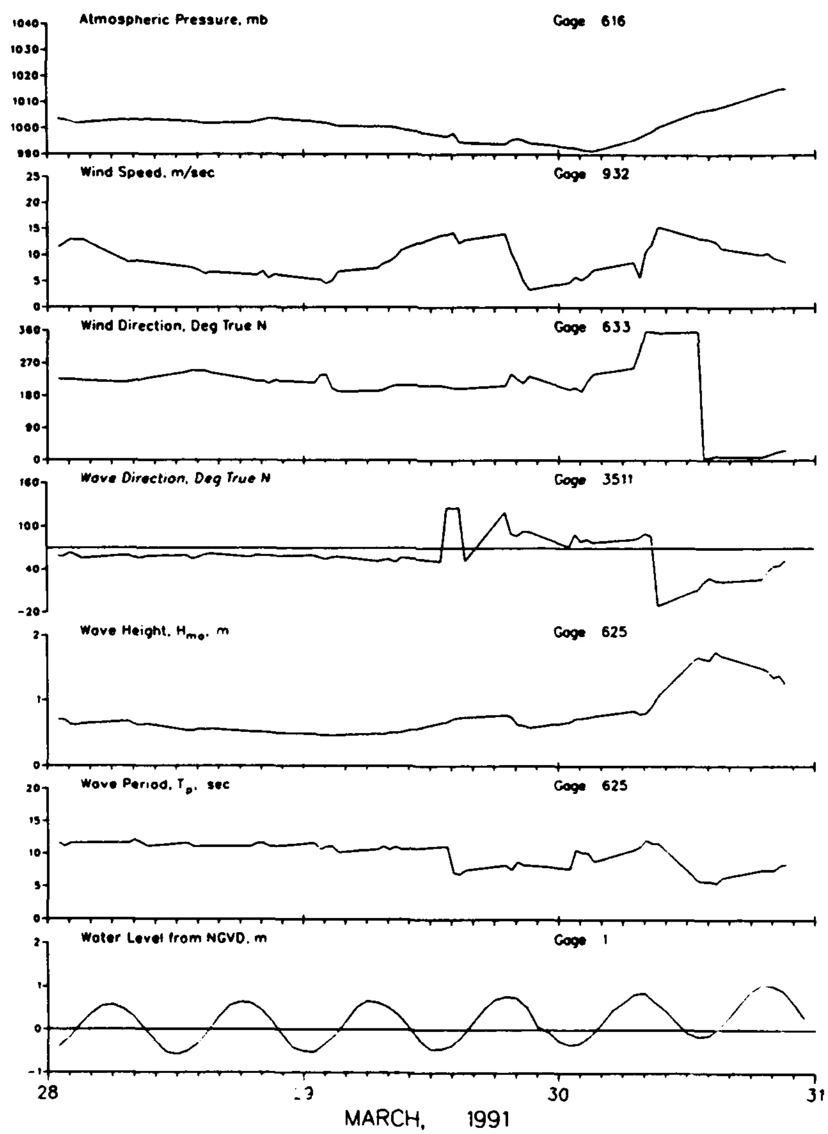


Figure 31. Data for 29 March 1991 storm

20-21 April 1991 (Figure 32)

70. Developing off Cape Hatteras, NC on 20 April, this intense coastal storm quickly deepened and moved up the coast, being located off the Maryland coast early on 21 April and over Canada by 22 April. Maximum wind speeds near 17 m/s (from the north-northeast) were recorded at 1600 EST on 20 April, with the maximum H_{mo} (at Gage 625) of 2.81 m (T_p = 8.83 sec) occurring several hours later at 2020 EST. This was followed the next morning at 0208 EST by the minimum atmospheric pressure of 998.4 mb. Total precipitation at the FRF from this system was 42 mm.

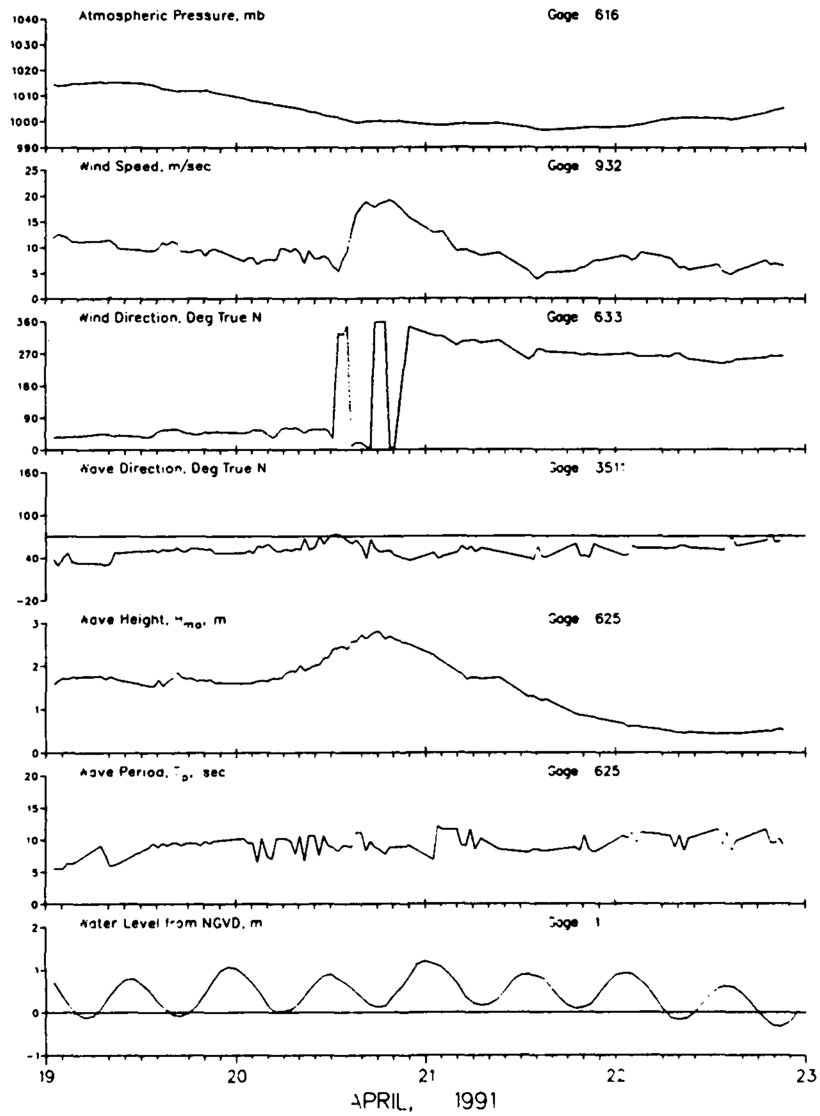


Figure 32. Data for 20-21 April 1991 storm

18-19 May 1991 (Figure 33)

71. Winds from a strong Canadian high-pressure system began to generate storm waves at the FRF late on 18 May. The maximum H_{mo} (at Gage 625) of 2.43 m (T_p = 6.92 sec) was attained at 1000 EST on 19 May. Maximum winds (from the northeast) neared 14 m/s at 0842 EST, also on 19 May.

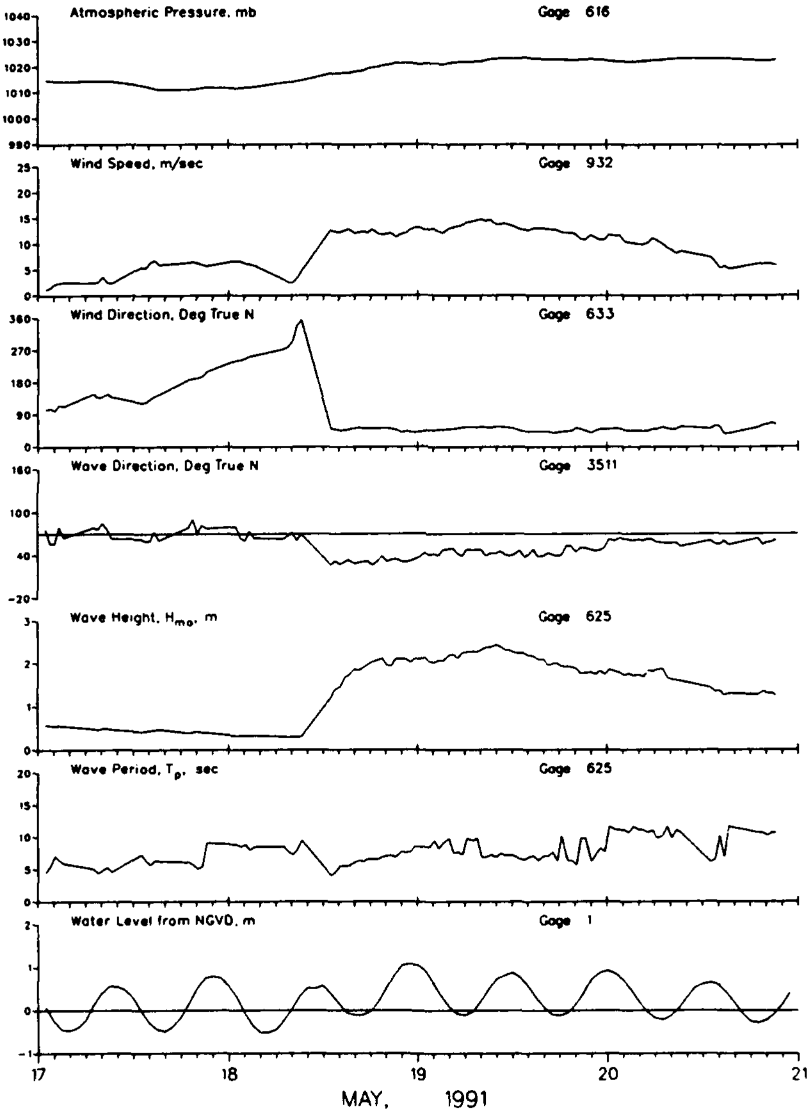


Figure 33. Data for 18-19 May 1991 storm

23 June 1991 (Figure 34)

72. Development of a weak coastal storm off the North Carolina coast early on 22 June produced a short period of storm waves. The maximum H_{mo} (at Gage 625) of 2.43 m (T_p = 8.26 sec) was attained at 2042 EST on 23 June. This coincided with the maximum winds (from the north-northeast) which exceeded 14 m/s and occurred at 2008 EST. The minimum atmospheric pressure of 1,006.3 mb was recorded on 22 June at 1900 EST. Total precipitation was 25 mm.

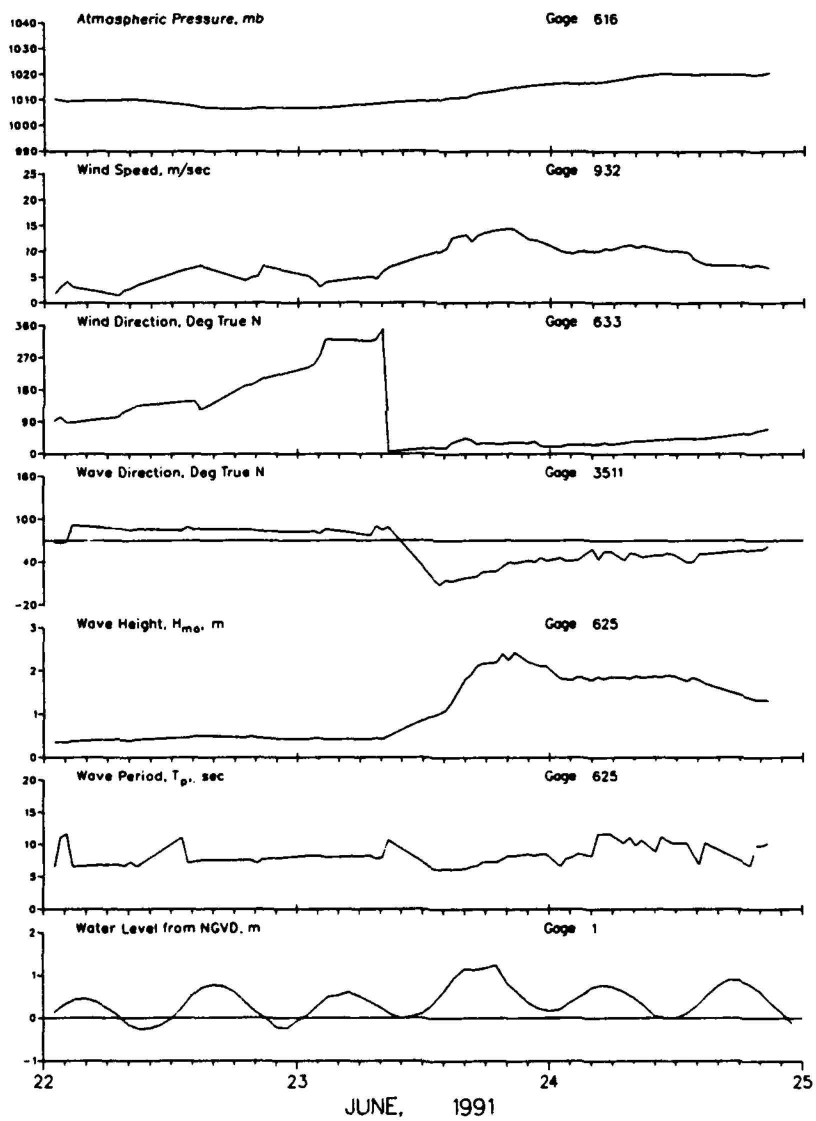


Figure 34. Data for 23 June 1991 storm

18-19 August 1991 -" Hurricane Bob" (Figure 35)

73. Bob reached tropical storm intensity on 16 August while located close to Bermuda and was upgraded to a hurricane on 17 August. The storm continued to intensify as it rapidly moved up the east coast, developing into a Category 3 hurricane (winds of 50 - 58 m/s (111 to 130 mph) on the Saffir/Simpson hurricane scale) as the eye passed 25 - 30 miles (40 - 48 km) east of Cape Hatteras, NC early on 19 August. Continuing up the coast, the storm finally made landfall on the Rhode Island coast late on 19 August. The maximum H_{mo} (at Gage 630) of 4.83 m (T_p = 15.06 sec) was recorded at 2342 EST on 18 August. Maximum onshore winds (from the northeast) approached 15 m/s occurring several hours earlier at 1934 EST. Peak winds (from the northwest) exceeded 23 m/s near midnight on 18 August. This coincided with the minimum atmospheric pressure of 994.0 mb. Total precipitation was 43 mm.

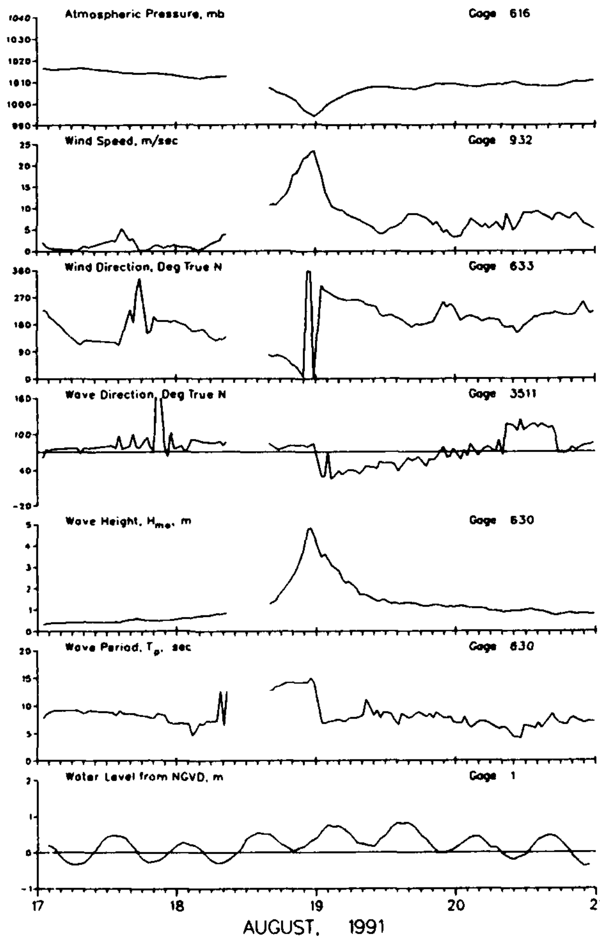


Figure 35. Data for Hurricane Bob, 18-19 August 1991

25 August 1991 (Figure 36)

74. A Canadian high-pressure system briefly produced storm waves at the FRF on 25 August. Maximum winds (from the northeast) exceeding 13 m/s peaked at 1708 EST on 25 August, with the maximum H_{mo} (at Gage 625) of 2.19 m (T_p = 6.40 sec) occurring several minutes later at 1742 EST.

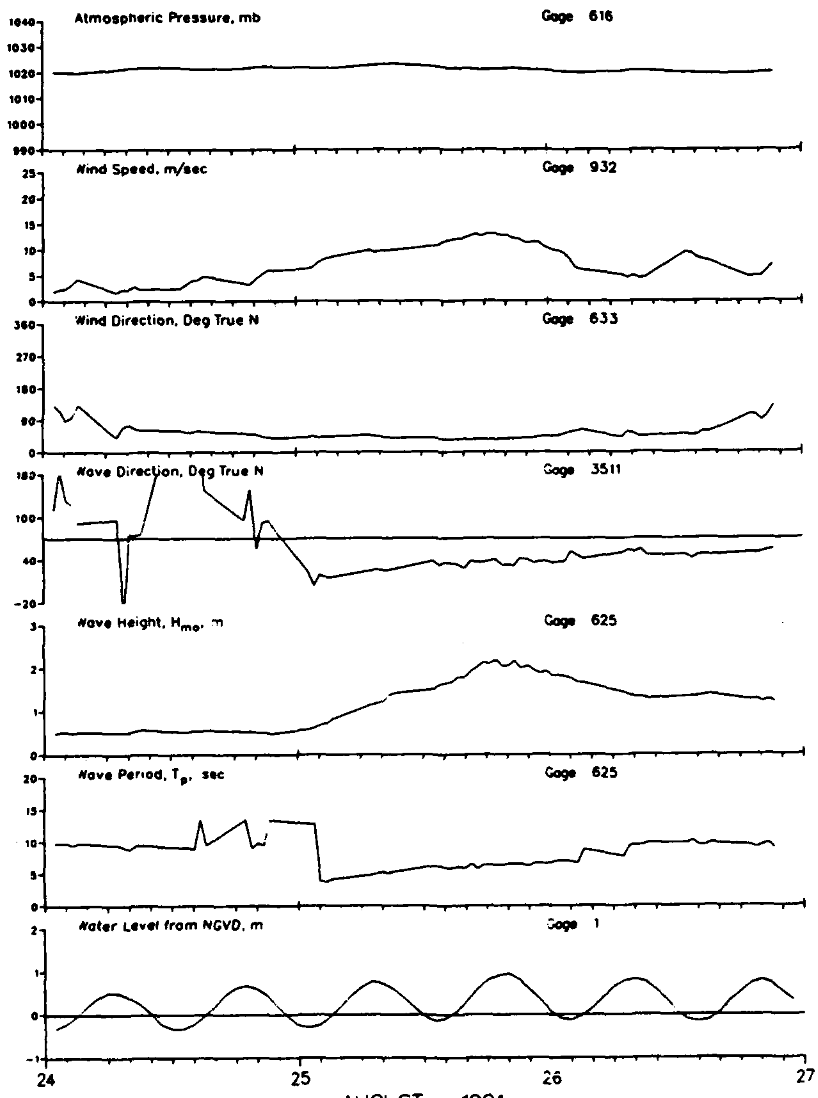


Figure 36. Data for 25 August 1991 storm

1-2 September 1991 (Figure 37)

75. A strong Canadian high-pressure system generated storm waves at the FRF on 1-2 September. Maximum winds (from the northeast) approached 15 m/s peaking at 1300 EST on 1 September with the maximum H_{mo} (at Gage 625) of 2.47 m (T_p = 8.00 sec) occurring several hours later at 1742 EST.

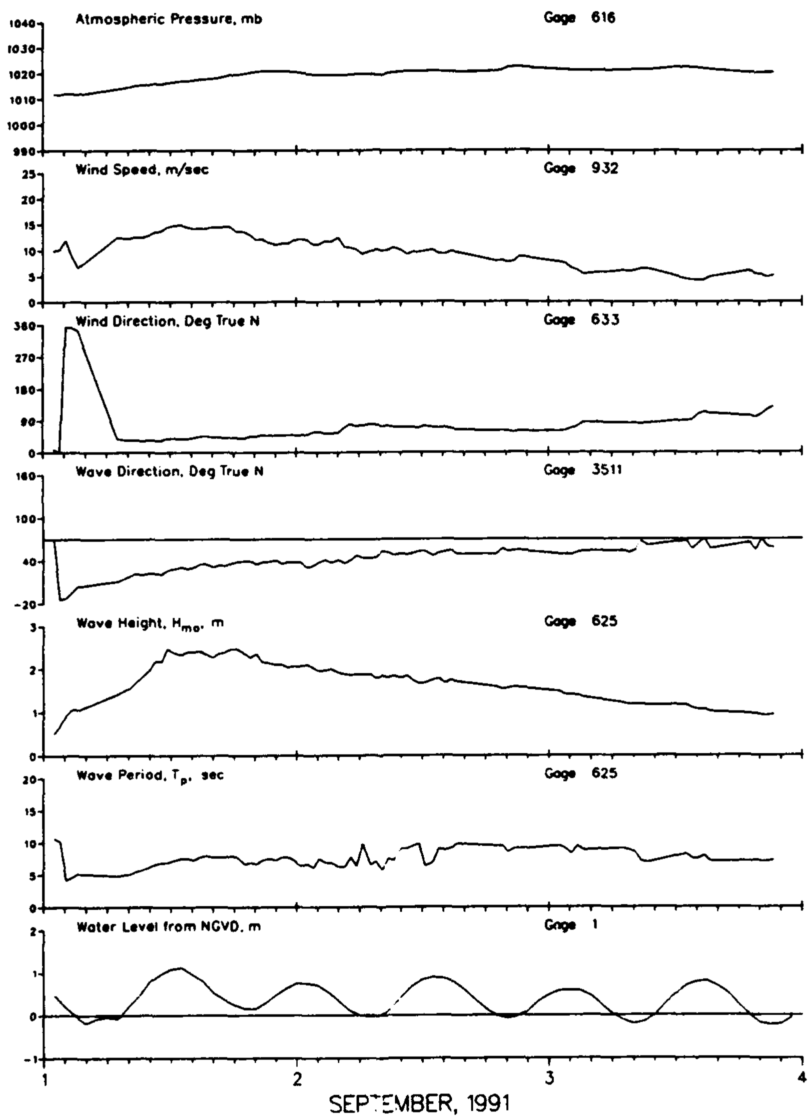


Figure 37. Data for 1-2 September 1991 storm

20 September 1991 (Figure 38)

76. A Midwestern high-pressure system briefly produced storm waves at the FRF on 20 September. Maximum winds (from the northwest) exceeding 16 m/s were recorded at 1000 EST on 20 September with the maximum H_{mo} (at Gage 625) of 2.28 m (T_p = 7.11 sec) occurring at 1216 EST.

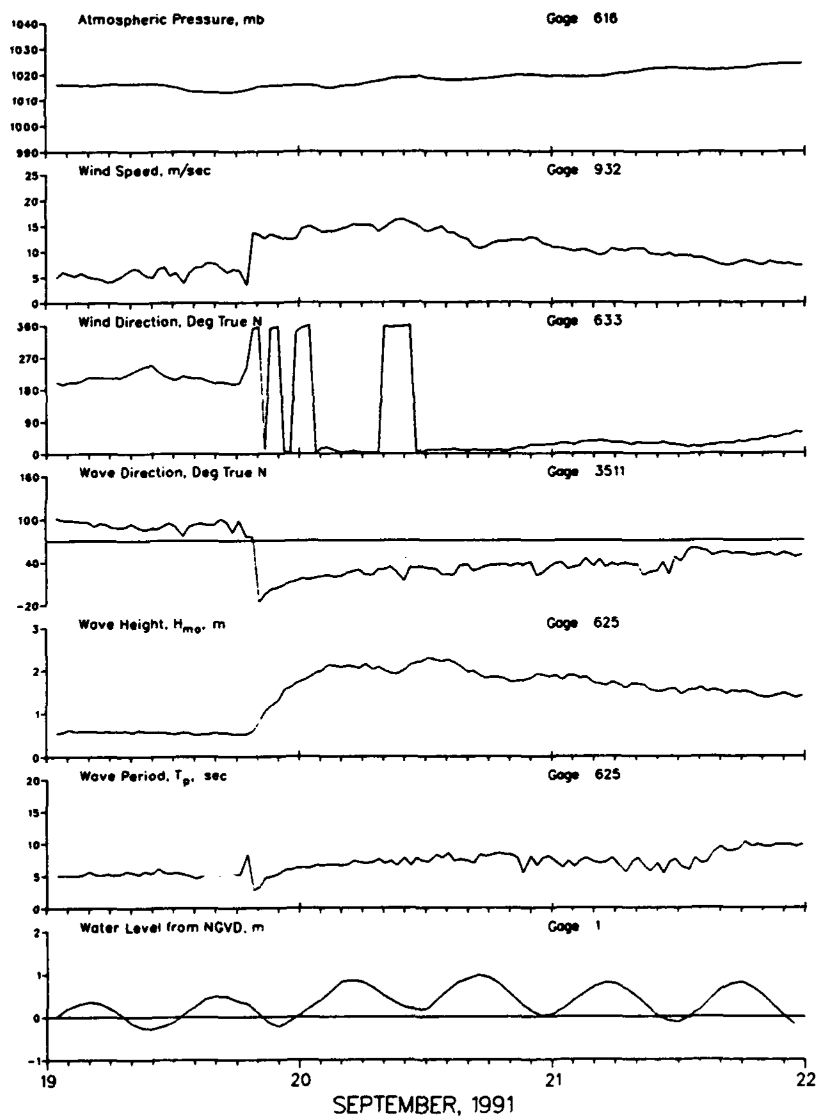


Figure 38. Data for 20 September 1991 storm

3 October 1991 (Figure 39)

77. Developing over southern Florida early on 1 October, this small coastal storm slowly moved up the eastern coast, being located off Cape Hatteras, NC on the morning of 3 October. Rapidly picking up speed, the storm was located off the Maine coast early the next day. The maximum H_{mo} (at Gage 625) of 2.34 m (T_p = 5.69 sec) occurred at 0916 EST on 3 October.

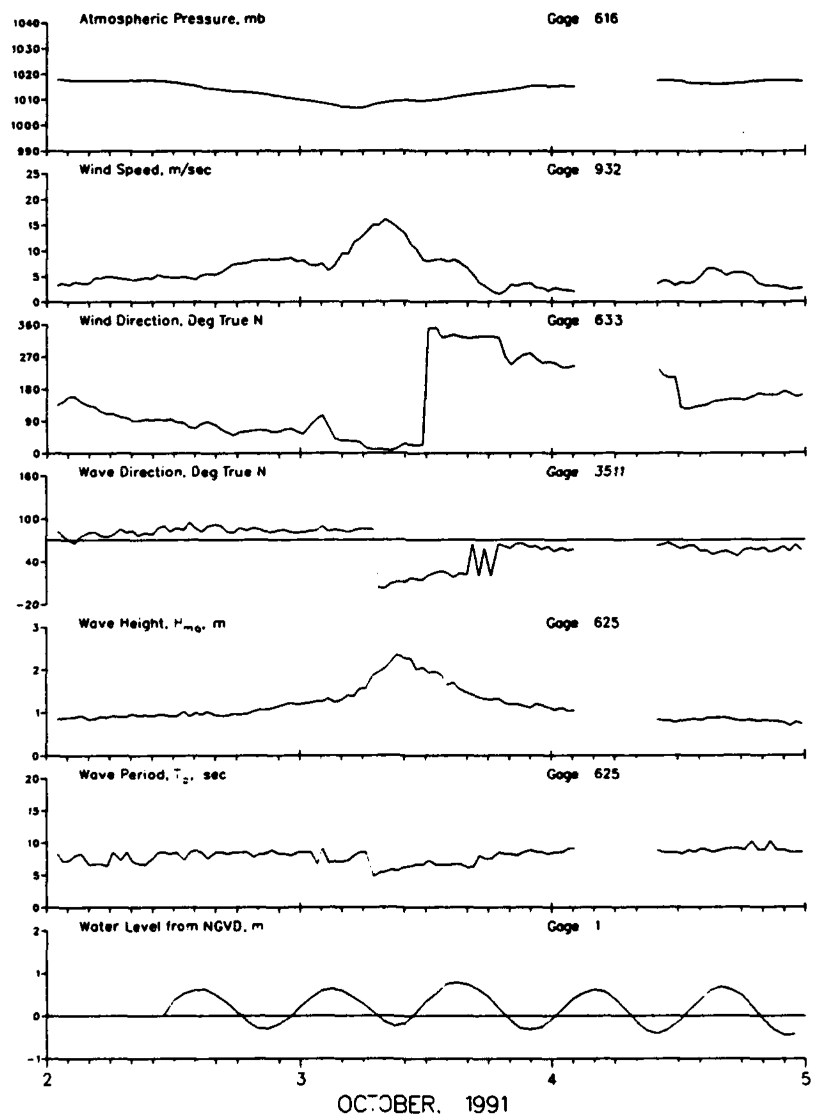


Figure 39. Data for 3 October 1991 storm

16-17 October 1991 (Figure 40)

78. Forming over Texas on 14 October this storm slowly travelled across the southeastern United States, moving into the Atlantic on 16 October. Located off South Carolina, the storm rapidly intensified beginning a northerly track up the coast. By 18 October the storm was located off the Maine coast. Peak onshore winds exceeding 15 m/s (from the northeast) were recorded at 2308 EST on 16 October with the maximum H_{mo} (at Gage 625) of 2.63 m (T_p = 7.31 sec) following at 2342 EST. The minimum atmospheric pressure of 1,004.7 mb occurred on 17 October at 0434 EST. Precipitation was 56 mm.

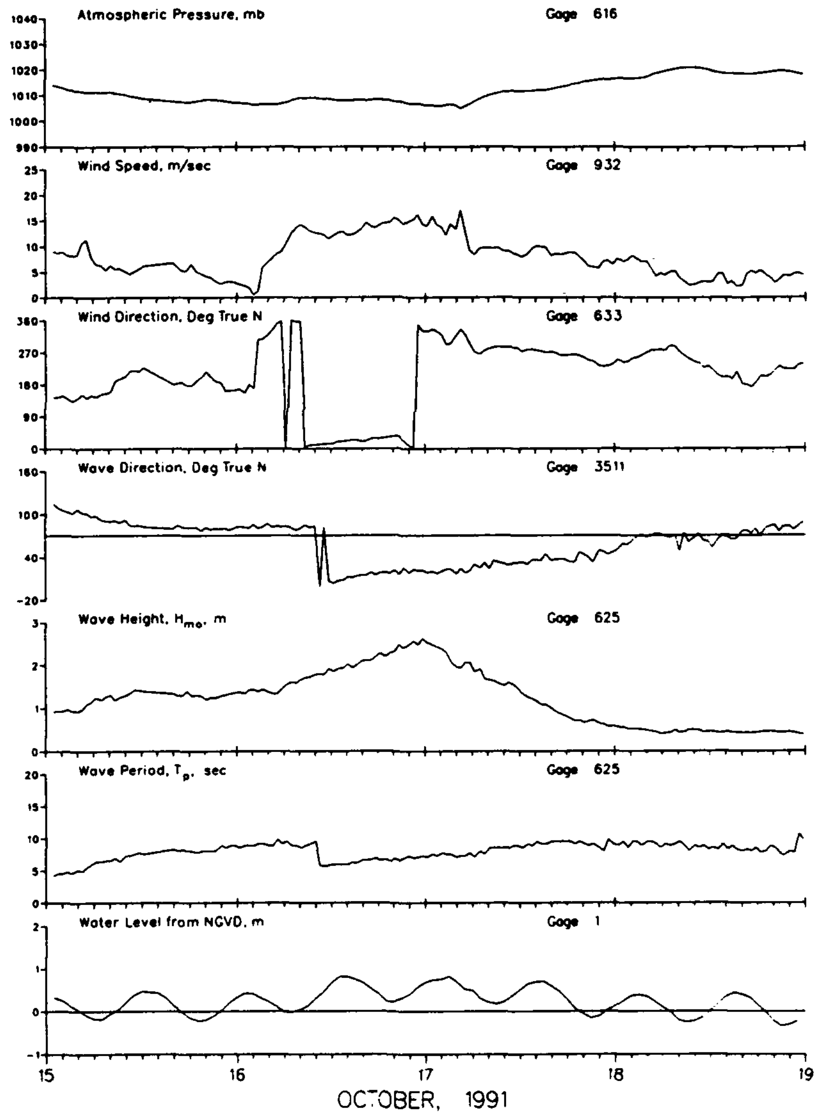


Figure 40. Data for 16-17 October 1991 storm

28 October - 1 November 1991 - "Halloween Storm" (Figure 41)

79. ("Halloween Storm") - This major storm, which was similar in many respects to the 1962 "Ash Wednesday" storm, was actually a sequence of events which began with a hurricane. Early on 27 October, Hurricane Grace approached the southeastern U.S. coast. While still well out to sea, Grace curved to the north, following a track that paralleled the coast but kept her well offshore. By the morning of 28 October, Grace was located approximately 1,000 kilometers east of the North Carolina coast where she encountered a strong easterly moving Canadian high-pressure system. The collision of these two systems produced high onshore winds at the FRF. Augmented by these strong winds, large waves, which were produced well offshore by Hurricane Grace, continued to build as they approached the North Carolina coast; wave heights recorded at the FRF increased throughout the day. Grace continued to track north, finally being absorbed by a low-pressure system located off Nova Scotia late on 29 October. The merging of these two systems produced a huge storm which, contrary to normal storm tracks, proceeded to slowly move to the southwest. Early on 30 October the storm was off the New England coast and generating hurricane-force winds with a central atmospheric pressure of 988 mb as it continued its slow southwesterly course. By the morning of 31 October the storm was located well off the Maryland shore; although still strong, it had begun to weaken with its southwesterly movement greatly reduced. November 1 found the storm reversing its course and moving back out to sea as it continued to weaken. By the morning of November 2, the storm had curved back to the north; however, by the time the storm crossed the Maine coast, it had weakened considerably.

80. Although only a few oceanfront structures on the Outer Banks were completely destroyed, there was heavy damage to the primary dune system as well as extensive flooding and ocean overwash. Much of the sediment removed from the dunes was deposited inland burying most of an oceanfront road, while the flooding made many other roads impassable for over a week. Much heavier damage was reported to areas north of the Outer Banks, especially along the New England coast.

81. Maximum wind speeds at the FRF approached 18 m/s at 1600 EST on 28 October while the maximum H_{mo} (at Gage 630) of 5.93 m (T_p = 19.69 sec) occurred at 0016 EST on 31 October. The minimum atmospheric pressure at the

FRF only fell to 1,004.7 mb. This was a result of the storm center remaining well offshore. There was no precipitation at the FRF from this storm.

82. This storm encompassed several interesting features. Waves with an H_{mo} above 2.0 m (at Gage 625) lasted for 101 consecutive hours. The maximum T_p reached 21.33 sec on 30 October, while waves with T_p above 15 sec (normally only associated with hurricanes) were recorded both on 30 and 31 October, long after Hurricane Grace had passed. The storm surge at the FRF approached 0.7 m, with the highest tide level reaching +1.53 m (NGVD) on 31 October.

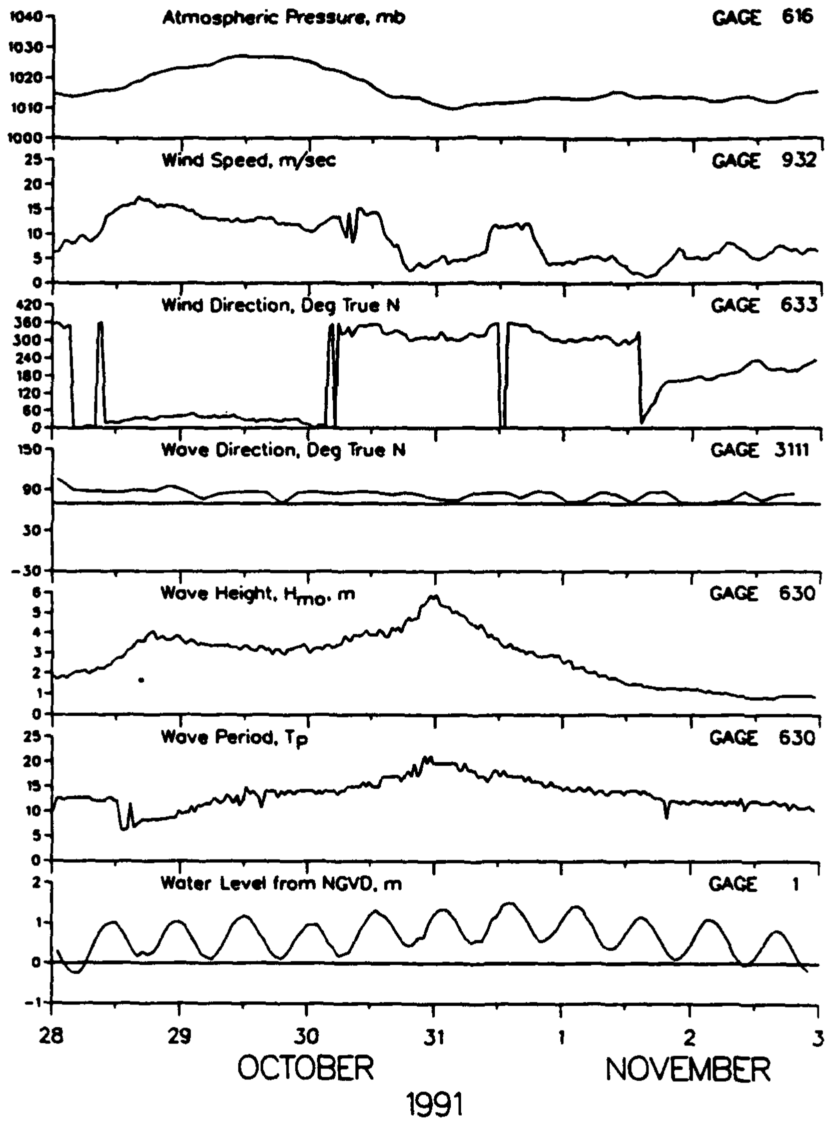


Figure 41. Data for 28 October-1 November 1991 storm

8-10 November 1991 (Figure 42)

83. Developing off Florida on 7 November, this storm slowly moved up the coast being located near Cape Hatteras, NC early on 10 November and reaching New England by 12 November. Maximum wind speeds (from the northeast) exceeded 21 m/s at 1600 EST on 9 November followed by the peak H_{mo} (at Gage 625), which reached 3.49 m (T_p = 12.19 sec) at 2234 EST. The minimum atmospheric pressure of 1,003.3 mb was recorded at 0508 EST on 10 November. Total precipitation was 39 mm.

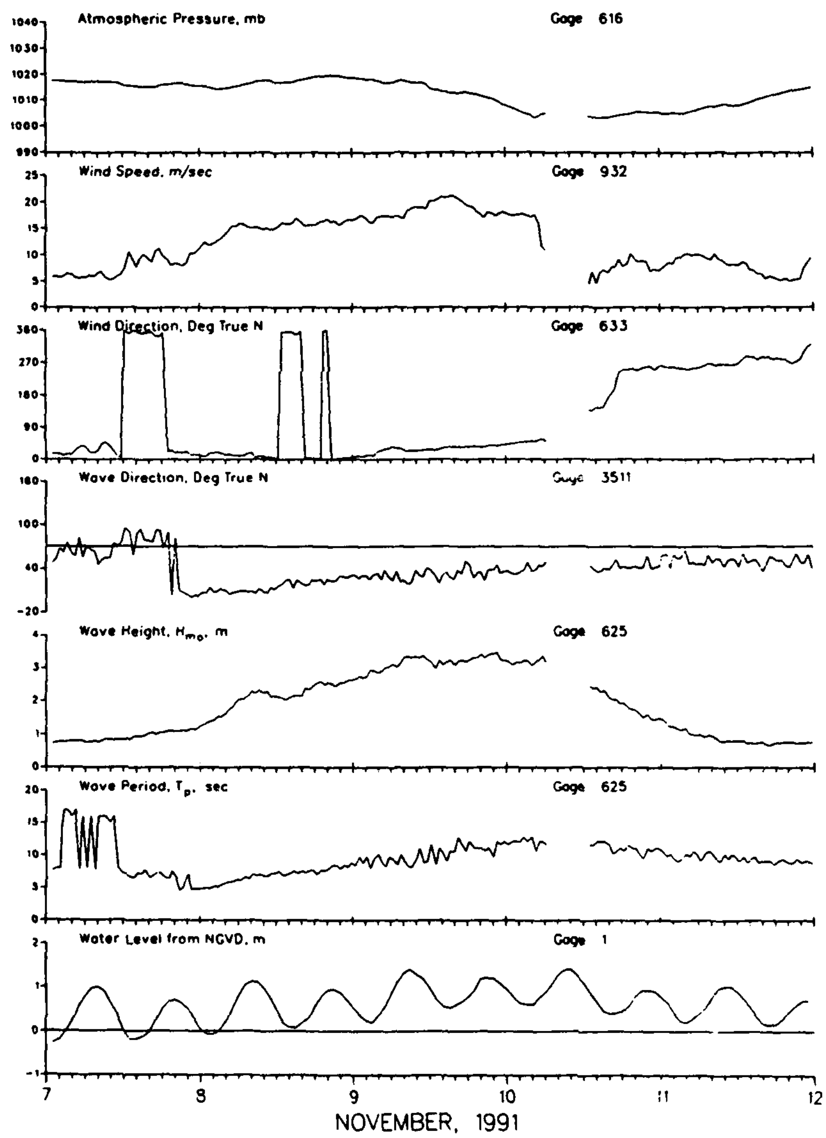


Figure 42. Data for 8-10 November 1991 storm

19 December 1991 (Figure 43)

84. A strong high-pressure system centered over the Great Lakes briefly generated storm waves at the FRF on 19 December. The peak wind speed (from the north-northwest) which surpassed 15 m/s was recorded at 1216 EST on 19 December. The maximum H_{mo} (at Gage 625) of 2.18 m (T_p = 7.31 sec) occurred several hours earlier at 1034 EST.

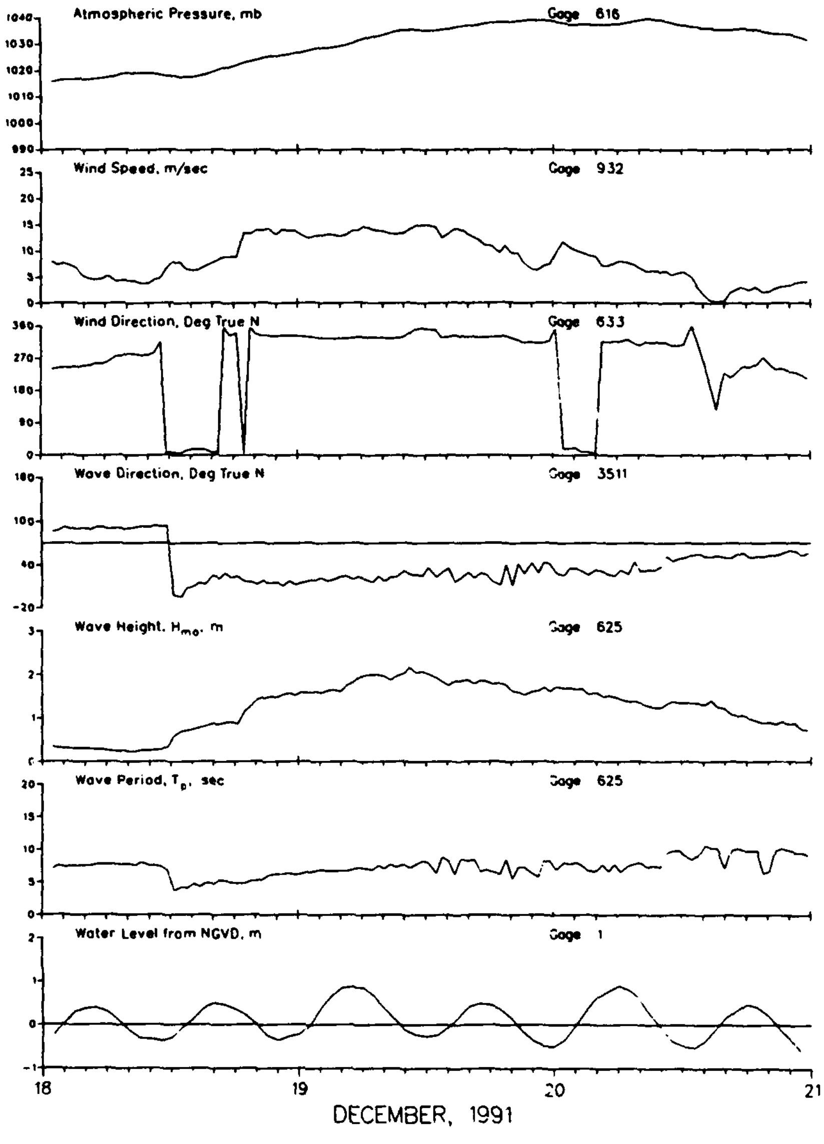


Figure 43. Data for 19 December 1991 storm

31 December 1991 (Figure 44)

85. Another strong high-pressure system centered over the Great Lakes again generated storm waves at the FRF for a brief time on 31 December. The peak wind speed (from the northeast) which exceeded 12 m/s, was recorded at 0734 EST on 31 December. The maximum H_{mo} (at Gage 625) of 2.07 m (T_p = 10.67 sec) occurred several hours later at 1742 EST.

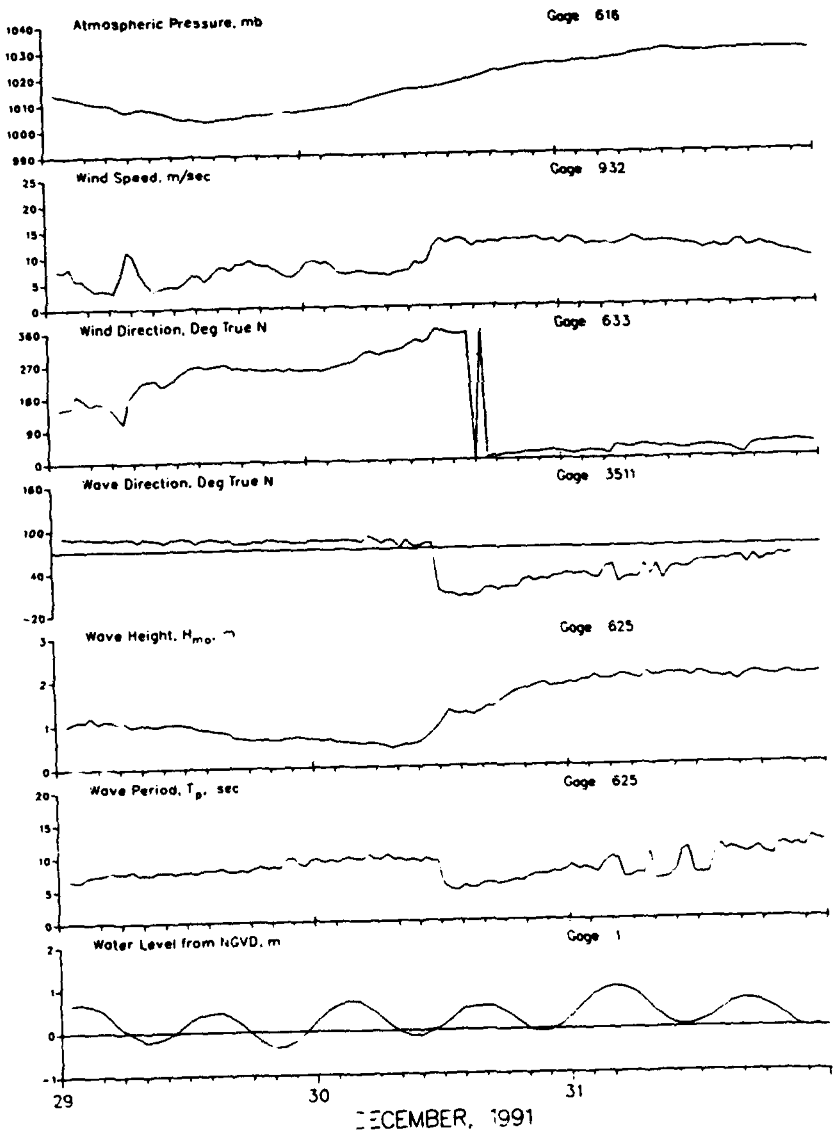


Figure 44. Data for 31 December 1991 storm

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APPENDIX A: SURVEY DATA

1. Contour diagrams constructed from the bathymetric survey data are presented in this appendix. The profile lines surveyed are identified on each diagram. Contours are in ½-meter increments referenced to the National Geodetic Vertical Datum (NGVD). The distance offshore is referenced to the Field Research Facility (FRF) monumentation baseline behind the dune.

2. Changes in FRF bathymetry diagrams constructed by contouring the difference between two contour diagrams are also presented with contour intervals of 0.25 m. Wide contour lines show areas of erosion. Other areas correspond to areas of accretion. Although these change diagrams are based on considerable interpolation of the original survey data, they do facilitate comparison of the contour diagrams.

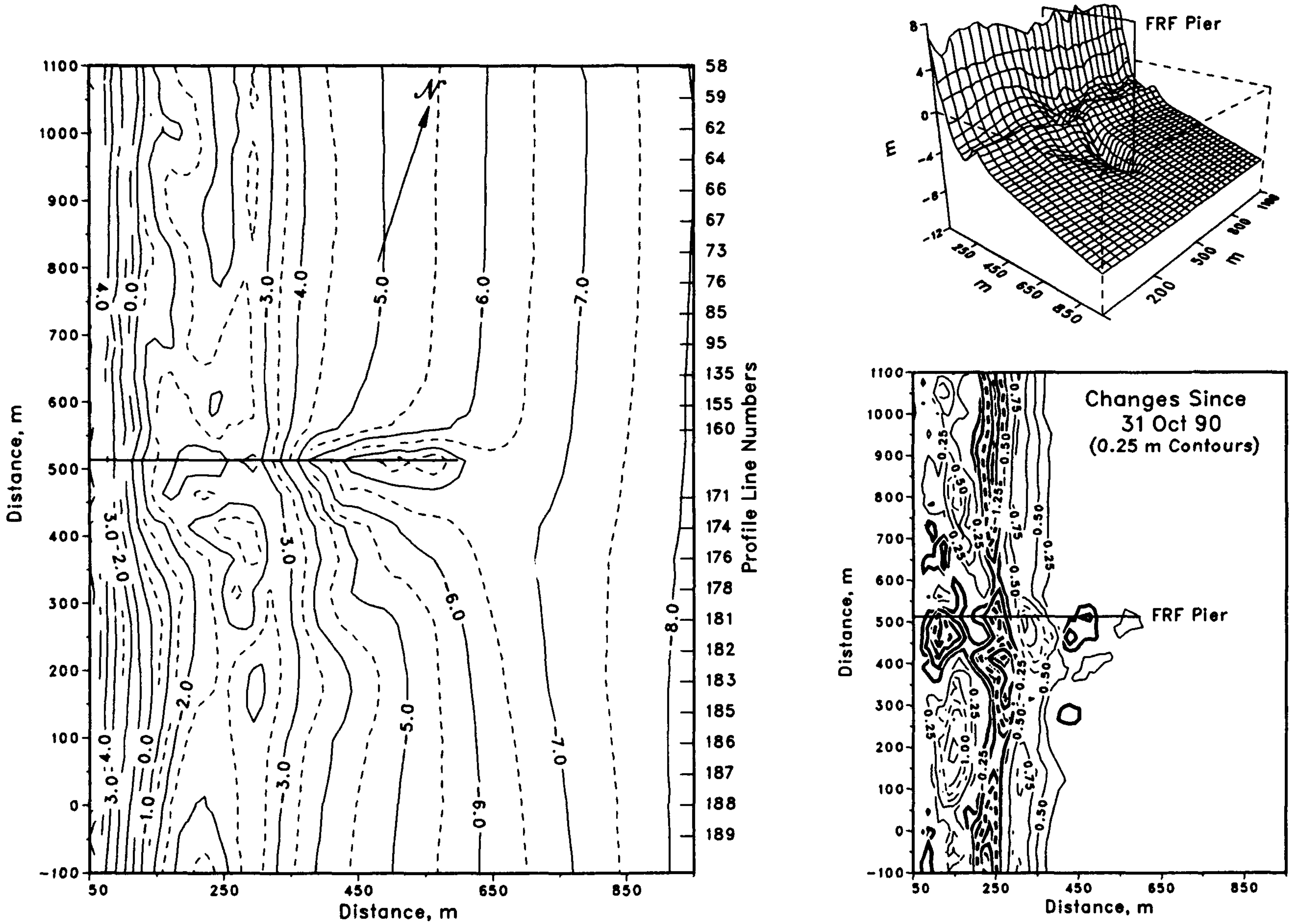


Figure A1. FRF Bathymetry 18 January 91 (depths relative to NGVD)

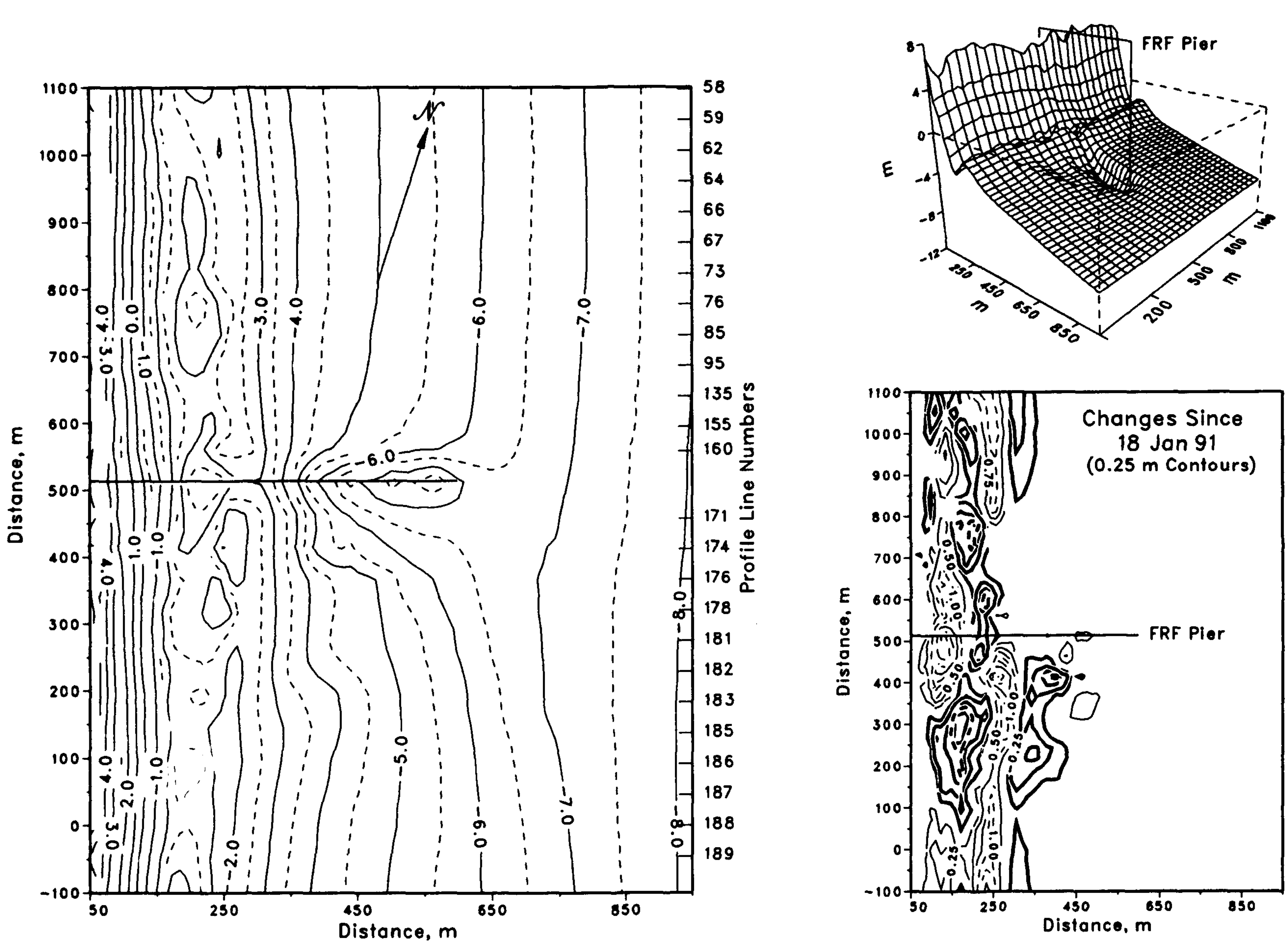


Figure A2. FRF Bathymetry 27 March 91 (depths relative to NGVD)

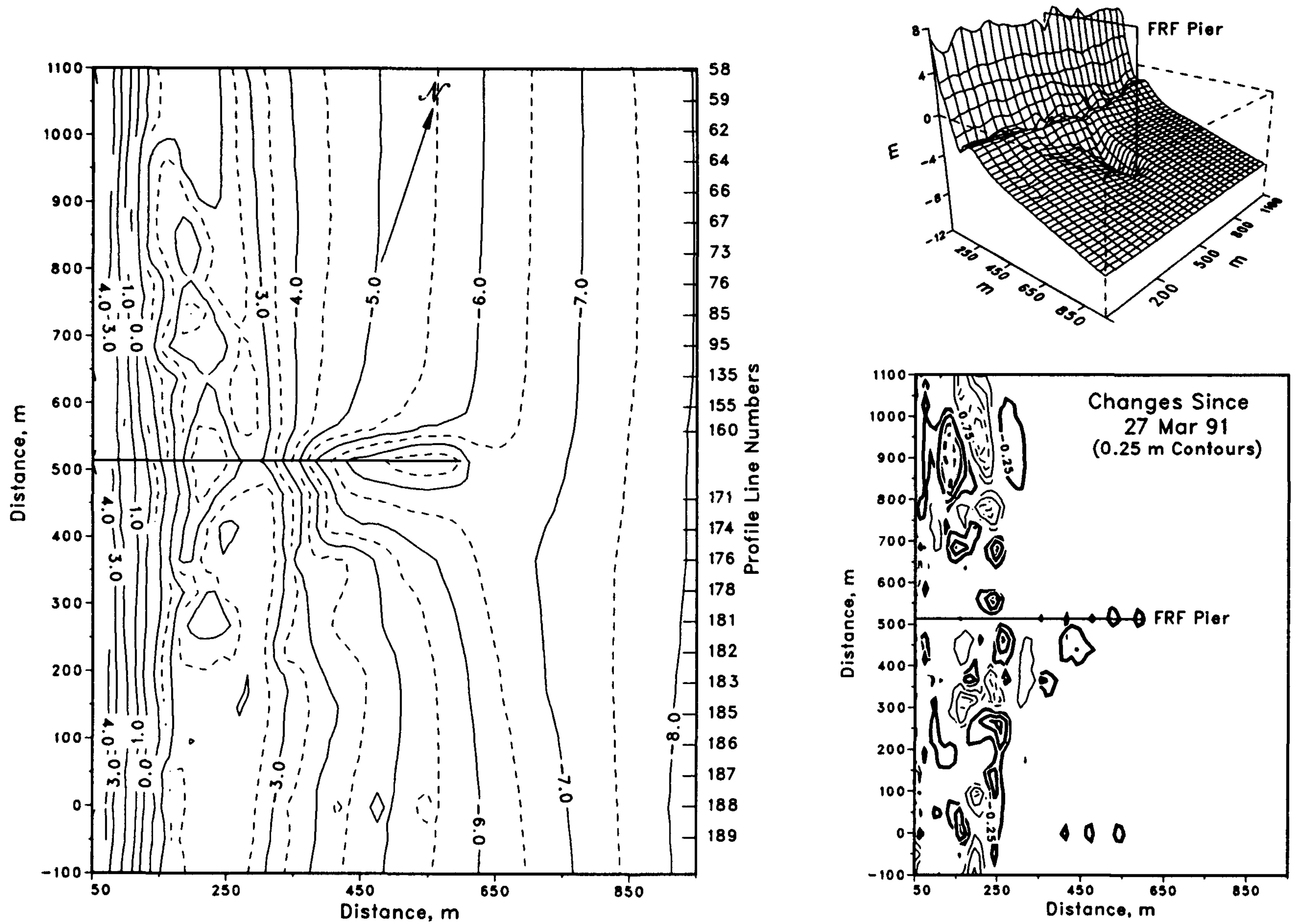


Figure A3. FRF Bathymetry 22 April 91 (depths relative to NGVD)

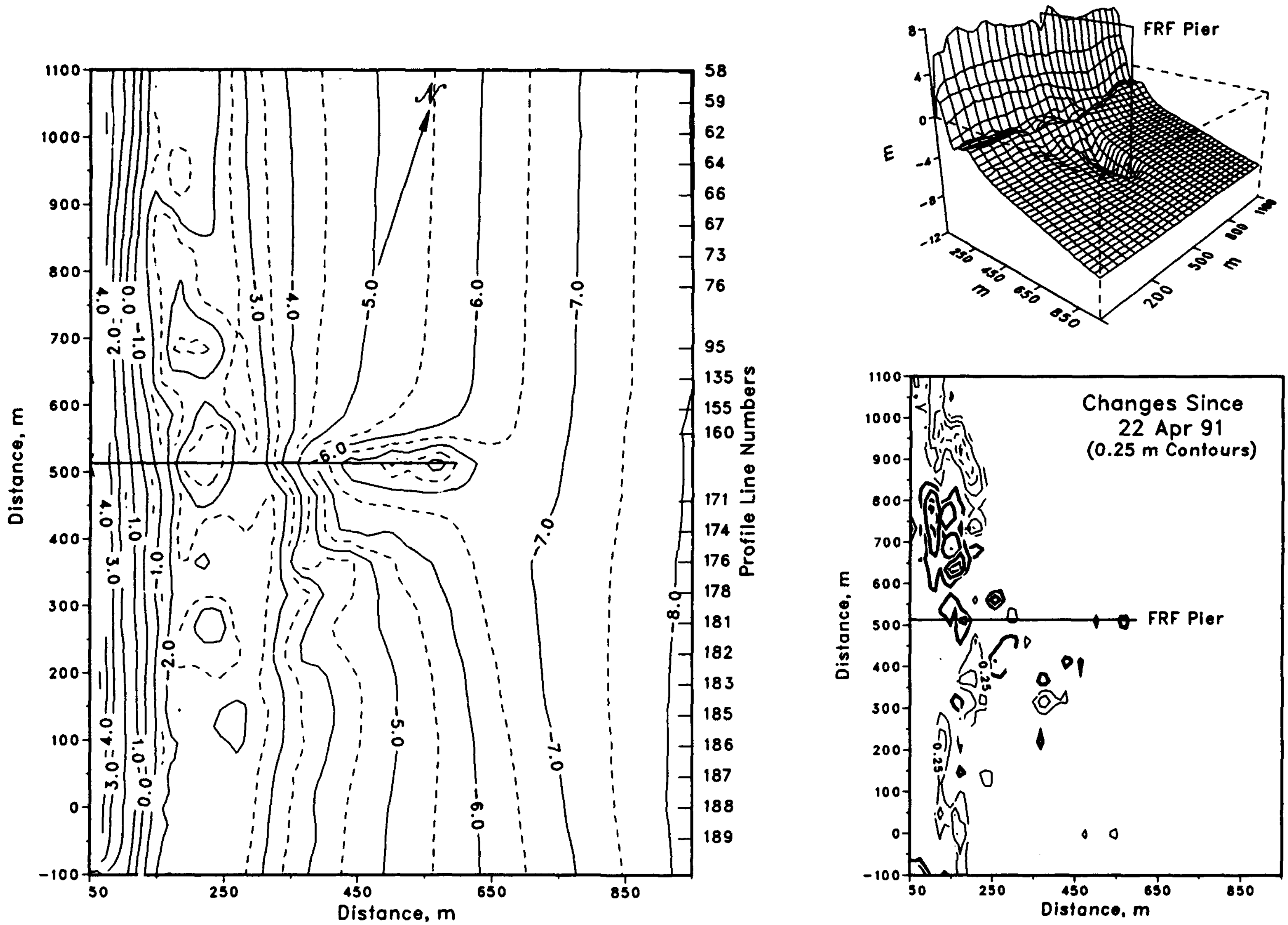


Figure A4. FRF Bathymetry 24 May 91 (depths relative to NGVD)

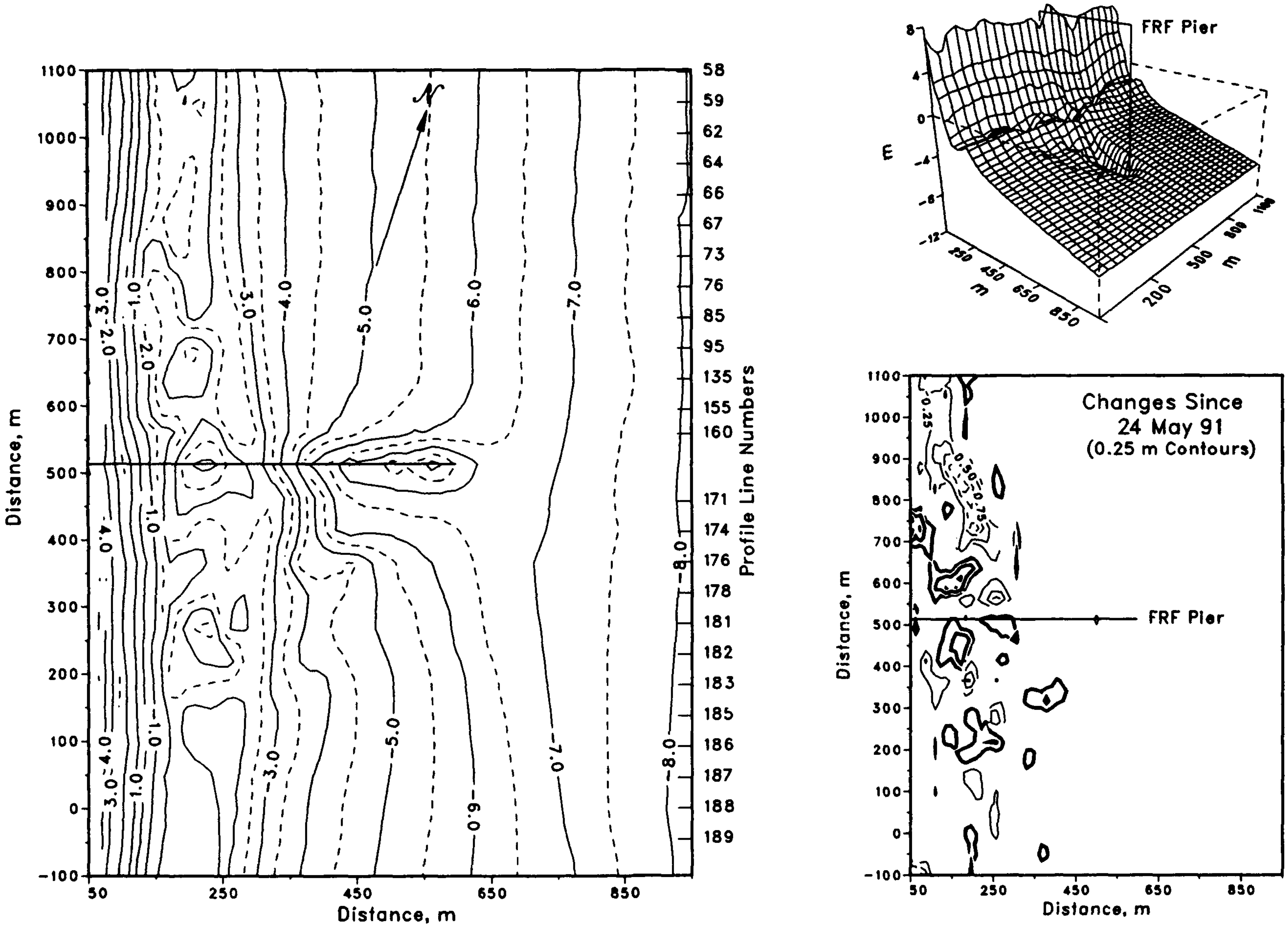


Figure A5. FRF Bathymetry 27 June 91 (depths relative to NGVD)

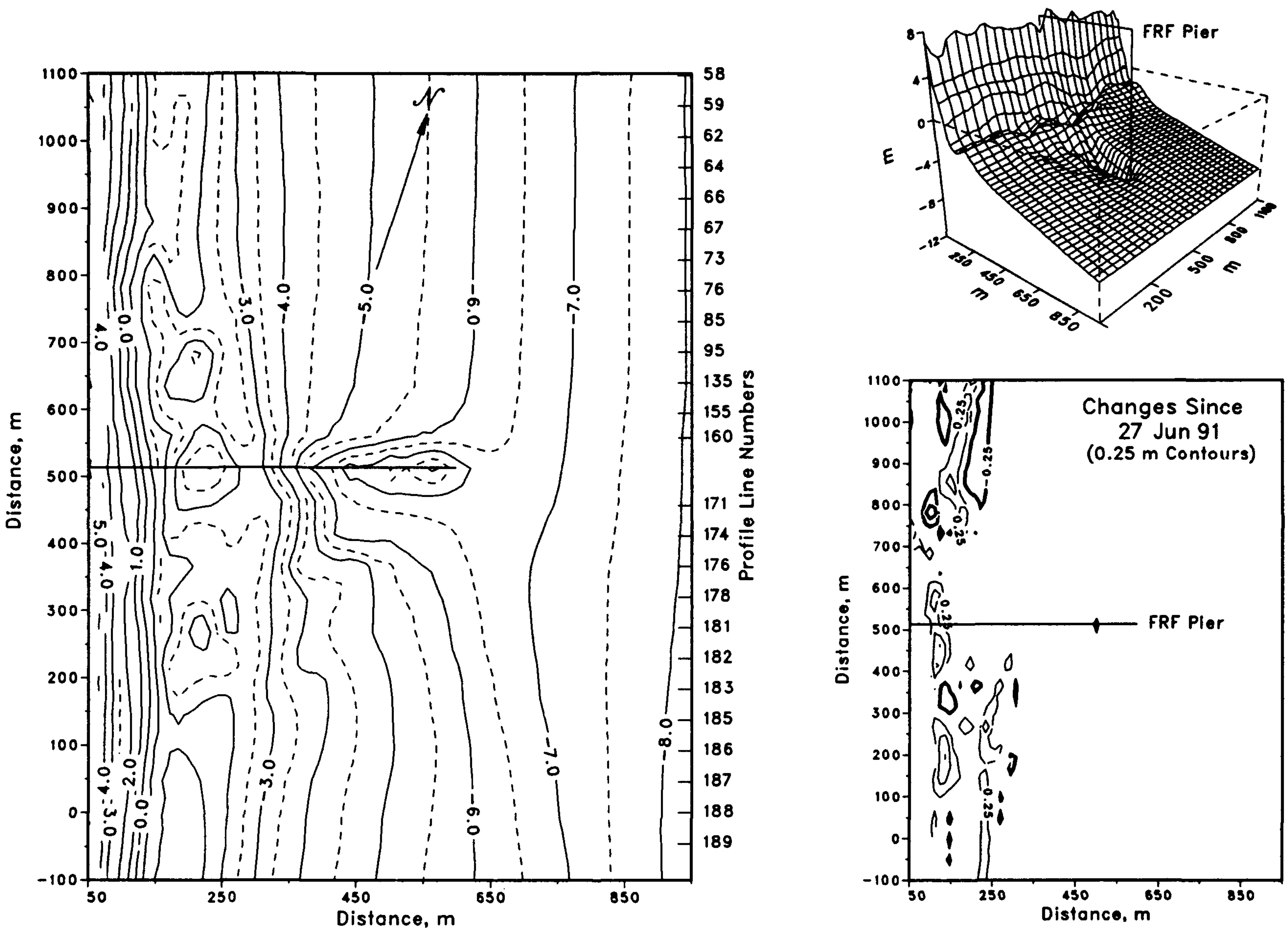


Figure A6. FRF Bathymetry 26 July 91 (depths relative to NGVD)

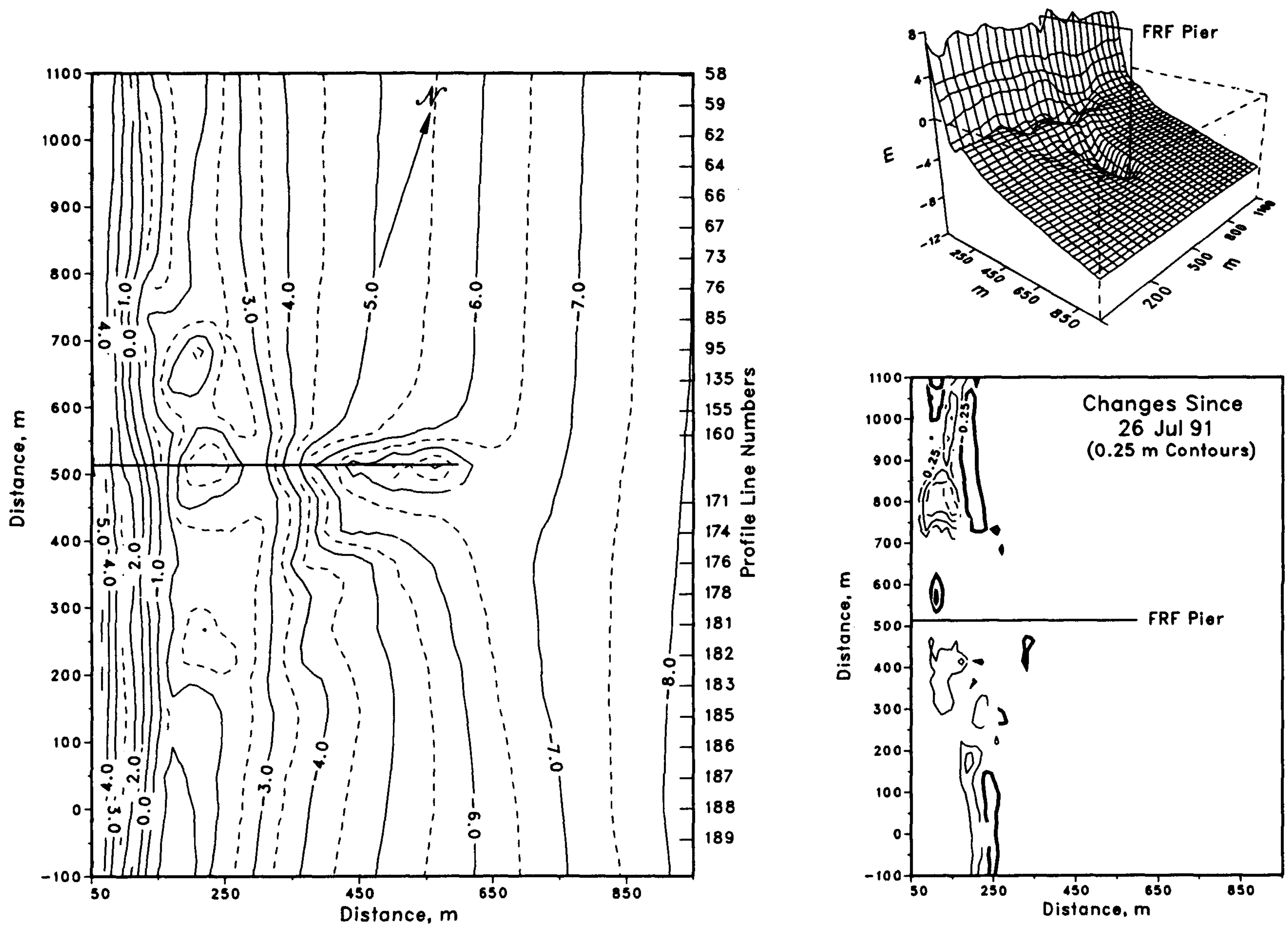


Figure A7. FRF Bathymetry 23 August 91 (depths relative to NGVD)

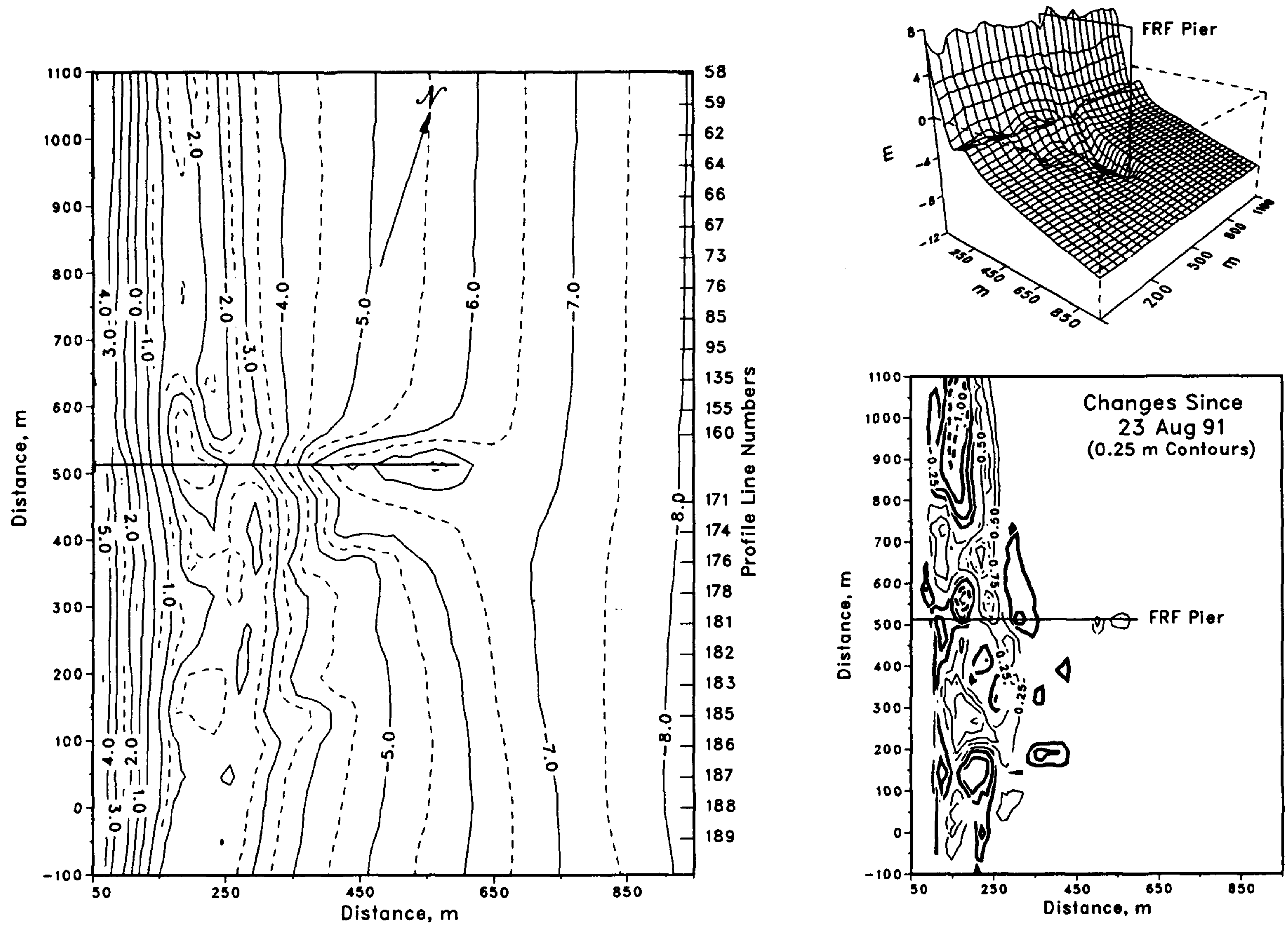


Figure A8. FRF Bathymetry 23 September 91 (depths relative to NGVD)

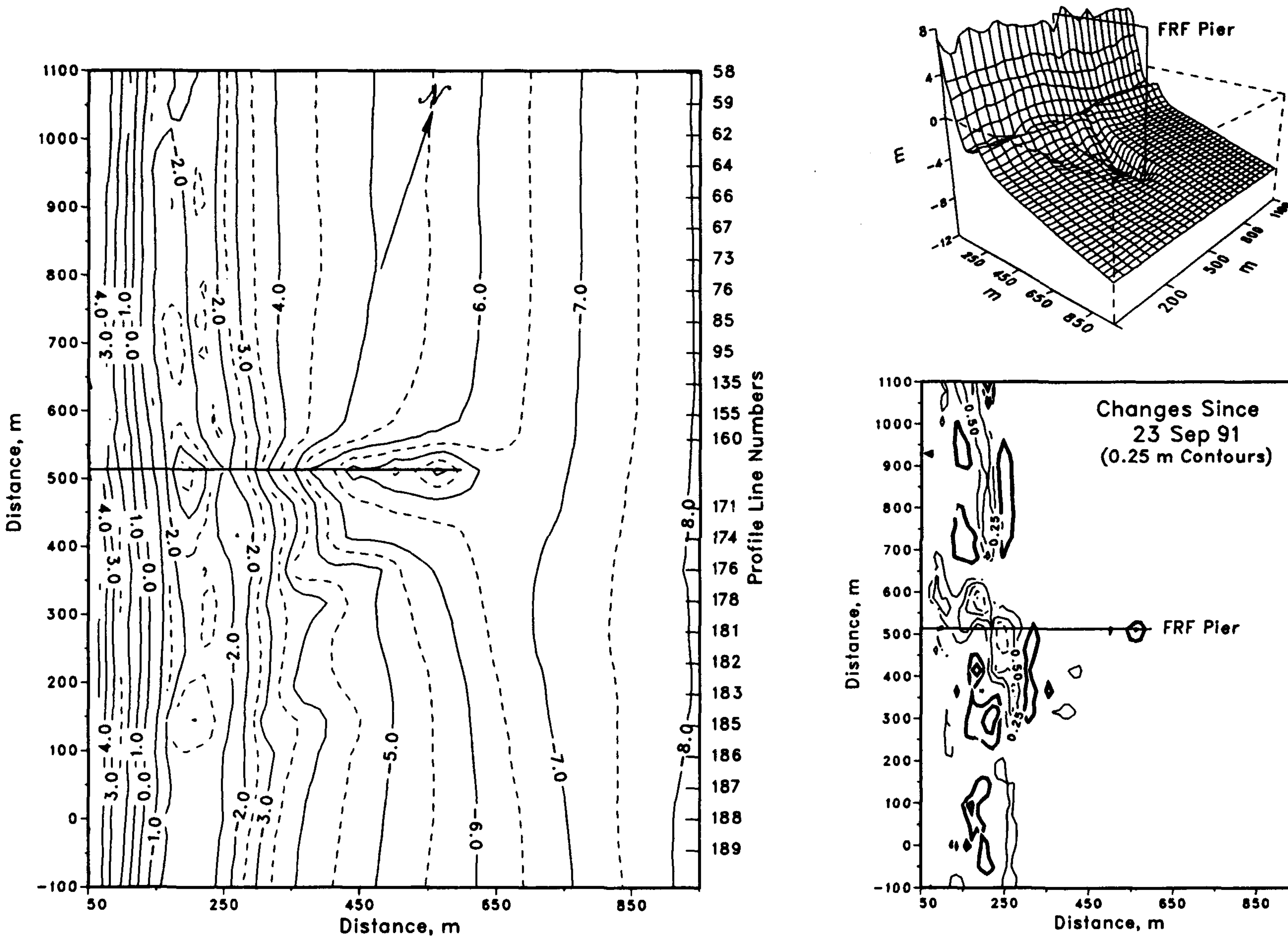


Figure A9. FRF Bathymetry 23 October 91 (depths relative to NGVD)

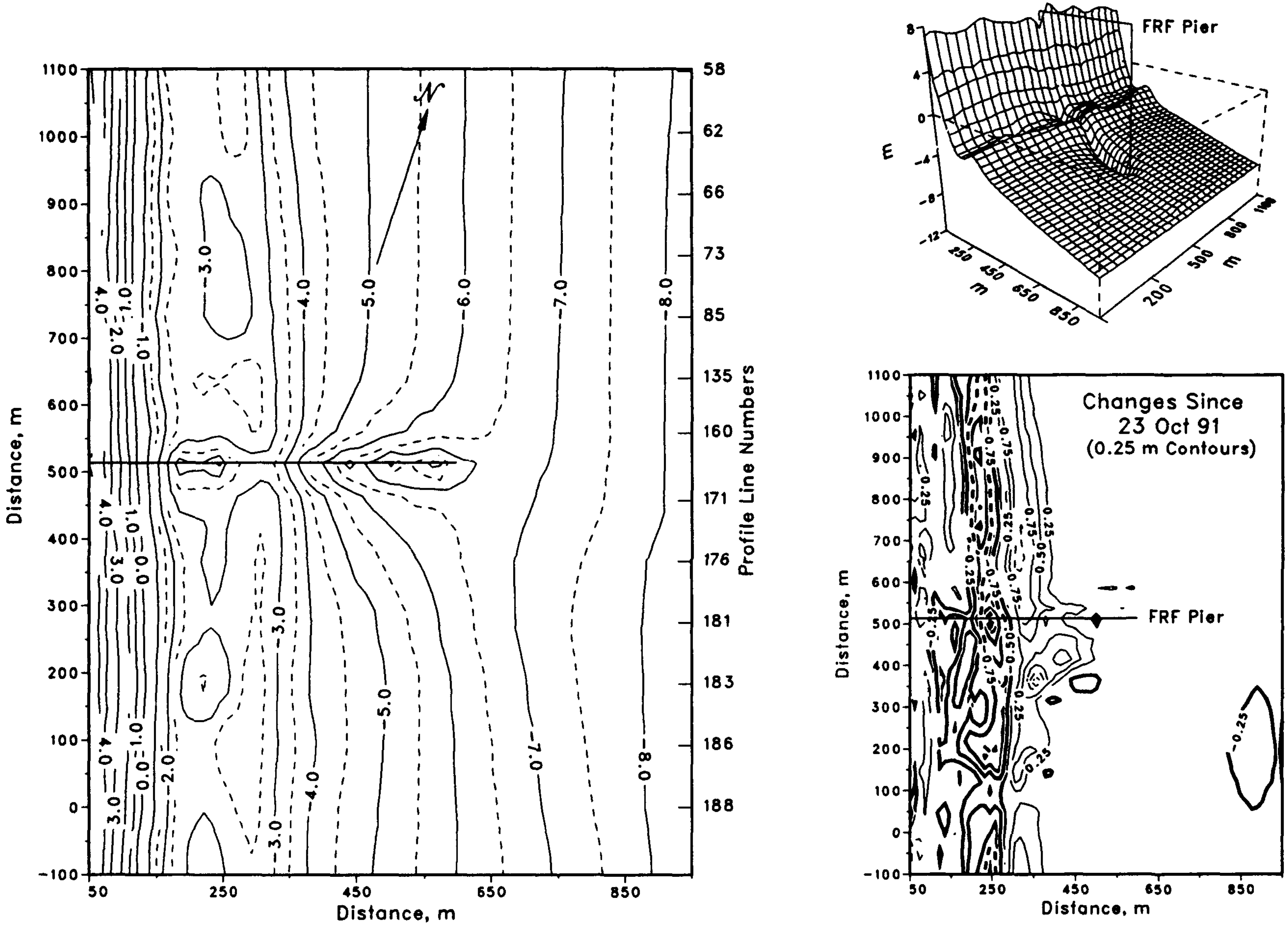


Figure A10. FRF Bathymetry 3 November 91 (depths relative to NGVD)

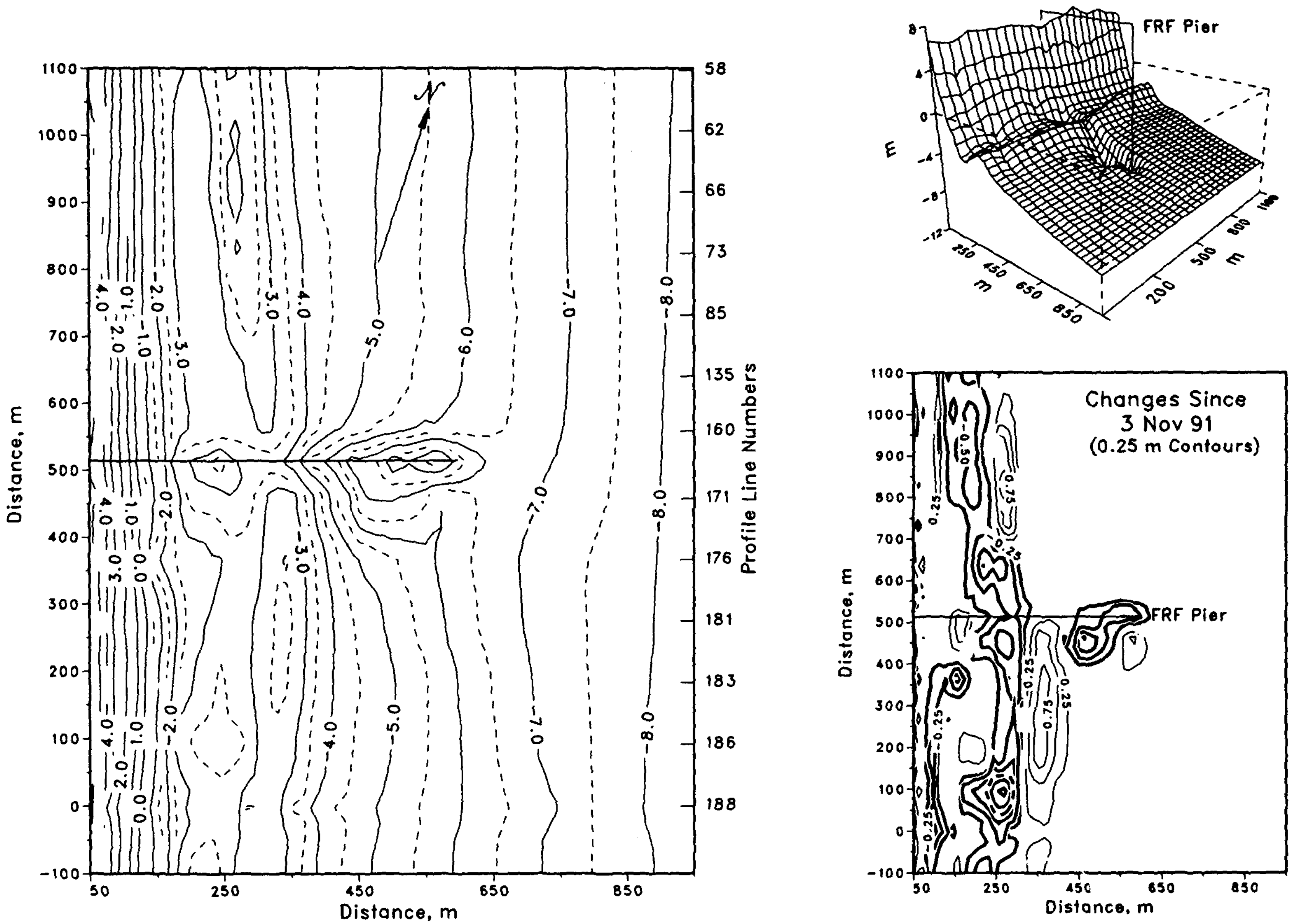


Figure A11. FRF Bathymetry 12 November 91 (depths relative to NGVD)

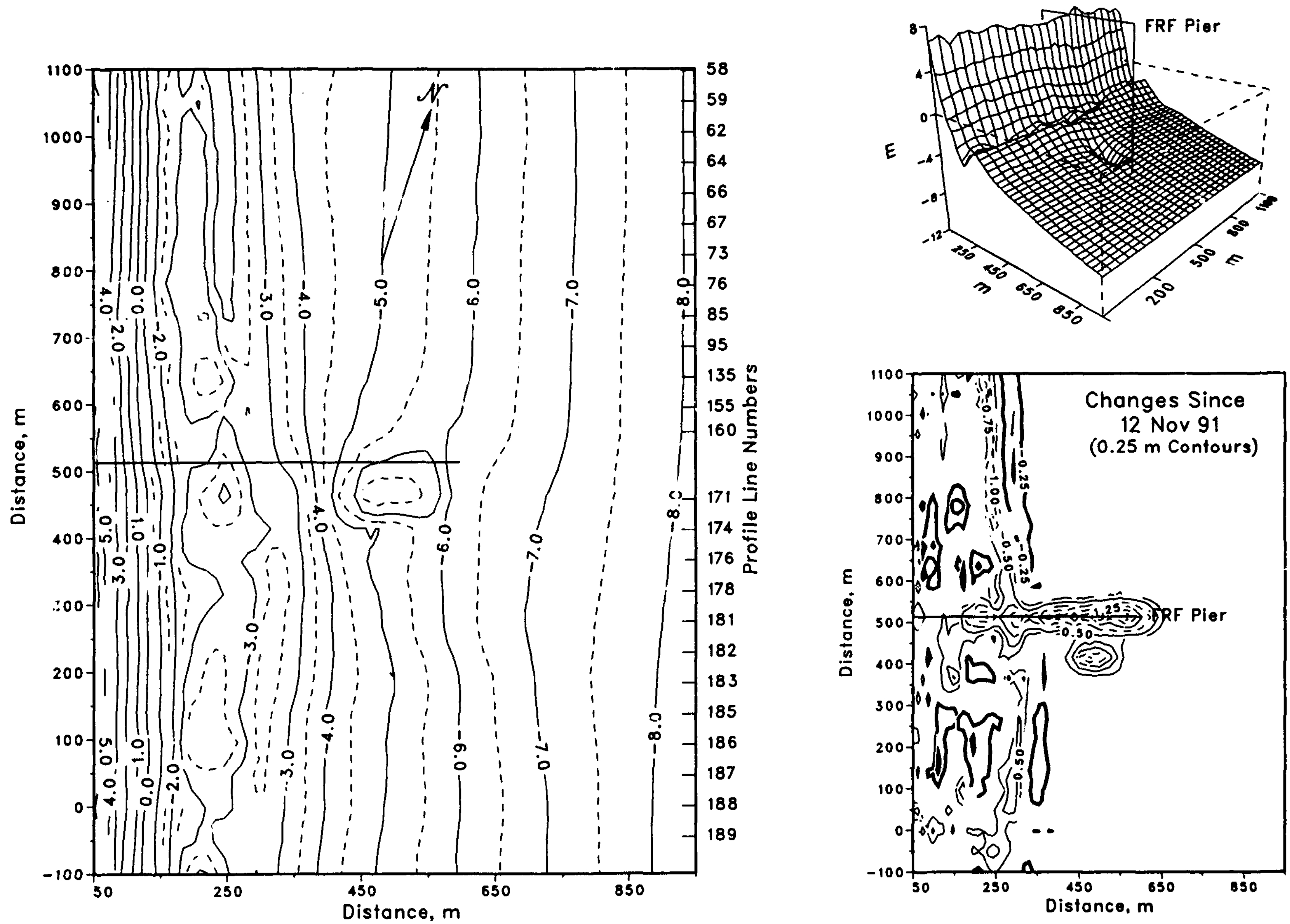


Figure A12. FRF Bathymetry 18 December 91 (depths relative to NGVD)

APPENDIX B: WAVE DATA FOR GAGE 630

1. Wave data summaries for Gage 630 are presented for 1991 and for 1980 through 1991 in the following forms:

Daily H_{mo} and T_p

2. Figure B1 displays the individual wave height (H_{mo}) and peak spectral wave period (T_p) values, along with the monthly mean values.

Joint Distributions of H_{mo} and T_p

3. Annual and monthly joint distribution tables are presented in Tables B1 and B2, and data for 1980 through 1991 are in Tables B3 and B4. Each table gives the frequency (in parts per 10,000) for which the wave height and peak period were within the specified intervals; these values can be converted to percentages by dividing by 100. Marginal totals are also included. The row total gives the number of observations out of 10,000 that fell within each specified peak period interval. The column total gives the number of observations out of 10,000 that fell within each specified wave height interval.

Cumulative Distributions of Wave Height

4. Annual and monthly wave height distributions for 1991 are plotted in cumulative form in Figures B2 and B3. Data for 1980 through 1991 are plotted in Figure B4.

Peak Spectral Wave Period Distributions

5. Annual and monthly peak wave period T_p distribution histograms for 1991 are presented in Figures B5 and B6. Data for 1980 through 1991 are presented in Figure B7.

Persistence of Wave Heights

6. Table B5 shows the number of times in 1991 when the specified wave height was equaled or exceeded at least once during each day for the duration (consecutive days). Data for 1980 through 1991 are averaged and given in Table B6. An example is shown below:

Height	Consecutive Day(s) or Longer																	
m	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19+
0.5	18	15		14	13	12		11	10	9				8		7			
1.0	50	34	24	21	18	14	12	8	7	3			2						
1.5	41	19	8	6	2	1													
2.0	22	9	5	1															
2.5	10	5	2																
3.0	6	1																	
3.5		1																	
4.0	1																		

This example indicates that wave heights equaled or exceeded 1.0 m 50 times for at least 1 day; 34 times for at least 2 days; 24 times for at least 3 days, etc. Therefore, on 16 occasions the height equaled or exceeded 1.0 m for 1 day exactly (50 - 34 = 16); on 10 occasions for 2 days; on 3 occasions for 3 days, etc. Note that the height exceeded 1 m 50 times for 1 day or longer, while heights exceeded 0.5 m only 18 times for this same duration. This change in durations occurred because the longer durations of lower waves may be interspersed with shorter, but more frequent, intervals of higher waves. For example, one of the times that the wave heights exceeded 0.5 m for 16 days may have represented three times the height exceeded 1 m for shorter durations.

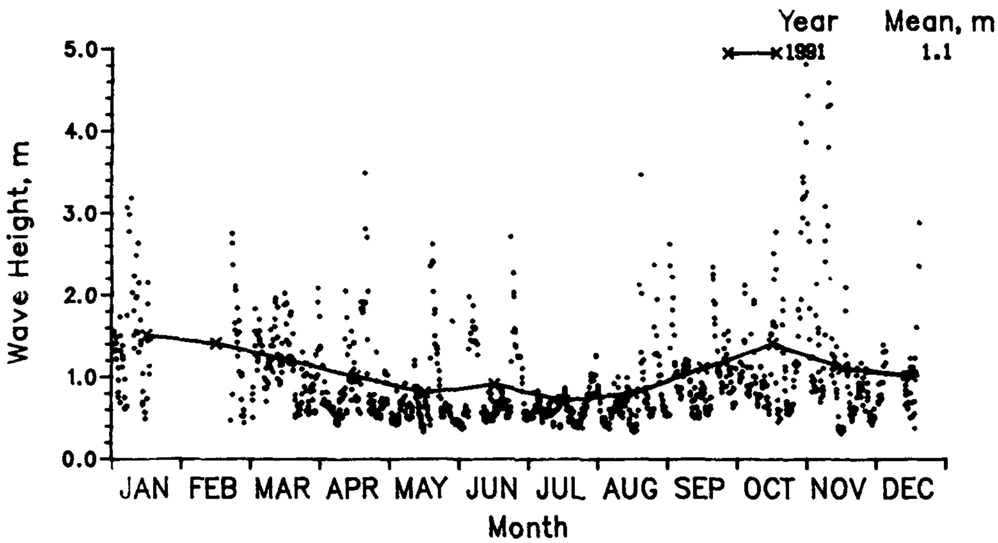
Spectra

7. Monthly spectra for the offshore Waverider buoy (Gage 630) are presented in Figure B8. The plots show "relative" energy density as a function of wave frequency. These figures summarize the large number of spectra for each month. The figures emphasize the higher energy density associated with storms, as well as the general shifts in energy density to different frequencies. As used here, "relative" indicates the spectra have been smoothed by the three-dimensional surface drawing routine. Consequently, extremely high- and low-energy density values are modified to produce a smooth surface. The figures are not intended for quantitative measurements; however,

they do provide the energy density as a function of frequency relative to the other spectra for the month.

8. Monthly and annual wave statistics for Gage 630 for 1991 and for 1980 through 1991 are presented in Table B7.

9. Figure B9 plots monthly time histories of wave height and period.



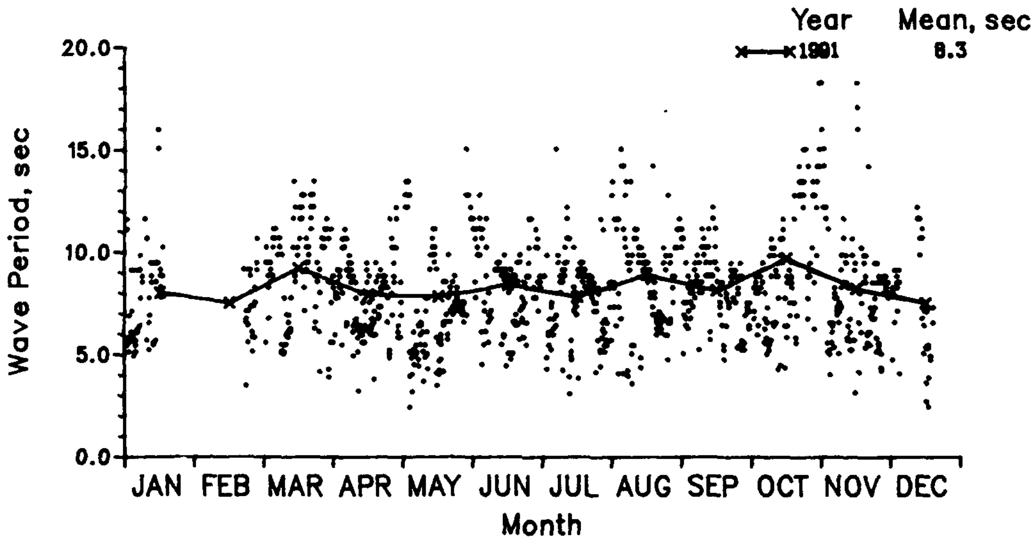


Figure B1. 1991 daily wave height and period values with monthly means for Gage 630

Table B1

Annual Joint Distribution of H_{mo} versus T_p

Annual 1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	8	17	17	50	50	84	319	243	168	34	126	25	1141
0.50 - 0.99	17	118	285	596	655	579	982	840	974	101	218	.	5365
1.00 - 1.49	.	.	84	437	269	193	537	218	176	25	92	.	2031
1.50 - 1.99	.	.	17	176	227	101	92	76	101	17	34	.	841
2.00 - 2.49	.	.	.	25	118	50	42	25	25	8	.	.	293
2.50 - 2.99	.	.	.	.	50	50	34	.	.	8	17	.	159
3.00 - 3.49	.	.	.	.	8	25	.	8	8	17	8	8	82
3.50 - 3.99	.	.	.	.	.	.	8	.	.	8	8	.	24
4.00 - 4.49	.	.	.	.	.	.	8	8	8	.	.	8	32
4.50 - 4.99	.	.	.	.	.	.	.	8	.	.	.	8	16
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	8	8
Total	25	135	403	1284	1377	1082	2022	1426	1460	218	503	57	

Table B2

Monthly Joint Distribution of H_{mo} versus T_p

January 1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	.	.	.	.	.	.	.	.	.	.	164	.	164
0.50 - 0.99	.	.	.	328	328	164	328	1311	.	.	164	.	2623
1.00 - 1.49	.	.	.	1803	492	.	492	164	492	.	.	.	3443
1.50 - 1.99	.	.	164	656	492	.	.	328	492	.	.	.	2132
2.00 - 2.49	.	.	.	164	.	328	.	164	164	.	.	.	820
2.50 - 2.99	.	.	.	.	.	.	492	.	.	.	.	.	492
3.00 - 3.49	.	.	.	.	.	164	.	.	164	.	.	.	328
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	0	0	164	2951	1312	656	1312	1967	1312	0	328	0	

February 1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	.	.	.	.	.	.	.	800	.	.	.	.	800
0.50 - 0.99	.	400	.	.	.	400	400	800	400	.	.	.	2400
1.00 - 1.49	.	.	.	800	.	1200	400	.	.	.	.	.	2400
1.50 - 1.99	.	.	.	800	400	400	400	400	.	.	.	.	2400
2.00 - 2.49	.	.	.	.	800	.	.	400	.	.	.	.	1200
2.50 - 2.99	.	.	.	.	400	400	.	.	.	.	.	.	800
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	0	400	0	1600	1600	2400	1200	2400	400	0	0	0	

March 1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	.	.	.	.	.	.	.	.	.	.	.	.	0
0.50 - 0.99	.	85	.	85	169	85	254	678	1780	85	424	.	3645
1.00 - 1.49	.	.	169	678	424	169	847	508	1102	85	508	.	4490
1.50 - 1.99	.	.	.	254	339	169	339	254	339	.	.	.	1694
2.00 - 2.49	.	.	.	85	.	.	.	.	85	.	.	.	170
2.50 - 2.99	.	.	.	.	.	.	.	.	.	.	.	.	0
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	0	85	169	1102	932	423	1440	1440	3306	170	932	0	

(Continued)

(Sheet 1 of 4)

Table B2 (Continued)

April 1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	.	.	.	.	.	.	250	250	.	.	.	.	500
0.50 - 0.99	.	167	167	667	1417	667	2000	583	1083	.	167	.	6918
1.00 - 1.49	.	.	.	333	333	.	500	167	.	.	.	.	1333
1.50 - 1.99	.	.	.	167	333	83	167	83	.	.	.	.	833
2.00 - 2.49	.	.	.	.	83	.	.	83	.	.	.	.	166
2.50 - 2.99	.	.	.	.	.	83	83	.	.	.	.	.	166
3.00 - 3.49	.	.	.	.	.	83	.	.	.	.	.	.	83
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	0	167	167	1167	2166	916	3000	1166	1083	0	167	0	

May 1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	.	82	164	328	246	.	82	246	656	164	738	.	2706
0.50 - 0.99	82	246	820	984	656	1557	328	410	328	82	246	.	5739
1.00 - 1.49	.	.	164	164	246	82	164	82	.	.	.	.	902
1.50 - 1.99	.	.	.	82	.	82	.	.	.	.	82	.	246
2.00 - 2.49	.	.	.	.	246	.	82	.	.	.	.	.	328
2.50 - 2.99	.	.	.	.	82	.	.	.	.	.	.	.	82
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	82	328	1148	1558	1476	1721	656	738	984	246	1066	0	

June 1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	.	.	.	94	.	94	377	566	283	.	.	.	1414
0.50 - 0.99	.	.	189	566	660	472	1415	1415	943	.	94	.	5754
1.00 - 1.49	.	.	94	189	94	377	377	94	189	.	.	.	1414
1.50 - 1.99	.	.	.	189	472	94	.	.	377	.	.	.	1132
2.00 - 2.49	.	.	.	.	.	.	189	.	.	.	.	.	189
2.50 - 2.99	.	.	.	.	.	94	.	.	.	.	.	.	94
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	0	0	283	1038	1226	1131	2358	2075	1792	0	94	0	

(Continued)

(Sheet 2 of 4)

Table B2 (Continued)

July 1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	.	.	.	.	172	345	1207	345	172	.	86	.	2327
0.50 - 0.99	.	259	603	1293	948	690	1638	1034	517	86	172	.	7240
1.00 - 1.49	.	.	.	86	86	86	172	.	.	.	.	.	430
1.50 - 1.99	.	.	.	.	.	.	.	.	.	.	.	.	0
2.00 - 2.49	.	.	.	.	.	.	.	.	.	.	.	.	0
2.50 - 2.99	.	.	.	.	.	.	.	.	.	.	.	.	0
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	0	259	603	1379	1206	1121	3017	1379	689	86	258	0	

August 1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	.	.	.	.	81	163	488	569	325	163	163	.	1952
0.50 - 0.99	.	163	488	325	976	244	407	1138	2439	163	163	.	6506
1.00 - 1.49	.	.	81	81	163	81	407	163	.	.	.	.	976
1.50 - 1.99	.	.	.	81	163	.	.	.	.	.	.	.	244
2.00 - 2.49	.	.	.	.	81	81	.	.	.	81	.	.	243
2.50 - 2.99	.	.	.	.	.	.	.	.	.	.	.	.	0
3.00 - 3.49	.	.	.	.	81	.	.	.	.	.	.	.	81
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	0	163	569	487	1545	569	1302	1870	2764	407	326	0	

September 1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	.	.	.	.	.	.	.	.	168	.	.	.	168
0.50 - 0.99	.	.	84	420	420	1092	1176	1176	756	.	84	.	5208
1.00 - 1.49	.	.	.	672	168	336	1429	504	168	.	.	.	3277
1.50 - 1.99	.	.	.	84	252	336	84	84	.	.	.	.	840
2.00 - 2.49	.	.	.	.	252	84	84	.	.	.	.	.	420
2.50 - 2.99	.	.	.	.	.	84	.	.	.	.	.	.	84
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	0	0	84	1176	1092	1932	2773	1764	1092	0	84	0	

(Continued)

(Sheet 3 of 4)

Table B2 (Concluded)

October 1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	.	.	.	.	.	164	82	.	.	.	82	.	328
0.50 - 0.99	.	.	164	246	328	164	1066	656	820	492	738	.	4674
1.00 - 1.49	.	.	82	328	410	82	738	246	.	82	82	.	2050
1.50 - 1.99	.	.	.	246	246	164	164	82	82	82	246	.	1312
2.00 - 2.49	.	.	.	82	82	82	82	.	.	.	.	.	328
2.50 - 2.99	.	.	.	.	246	.	.	.	.	82	82	.	410
3.00 - 3.49	.	.	.	.	.	.	.	82	.	164	82	82	410
3.50 - 3.99	.	.	.	.	.	.	.	.	.	82	82	.	164
4.00 - 4.49	.	.	.	.	.	.	82	.	.	.	.	82	164
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	82	82
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	82	82
Total	0	0	246	902	1312	656	2214	1066	902	984	1394	328	

November 1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	.	85	.	85	.	.	763	339	85	.	85	254	1696
0.50 - 0.99	.	.	254	1186	508	678	1017	424	424	85	.	.	4576
1.00 - 1.49	.	.	85	508	508	254	169	254	85	85	254	.	2202
1.50 - 1.99	.	.	.	169	169	.	85	.	.	85	.	.	508
2.00 - 2.49	.	.	.	.	169	85	.	.	85	.	.	.	339
2.50 - 2.99	.	.	.	.	85	85	.	.	.	.	85	.	255
3.00 - 3.49	.	.	.	.	.	85	.	.	.	.	.	.	85
3.50 - 3.99	.	.	.	.	.	.	85	.	.	.	.	.	85
4.00 - 4.49	.	.	.	.	.	.	.	85	85	.	.	.	170
4.50 - 4.99	.	.	.	.	.	.	.	85	.	.	.	.	85
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	0	85	339	1948	1439	1187	2119	1187	764	255	424	254	

December 1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	244	.	.	.	.	244	.	.	.	.	.	.	488
0.50 - 0.99	244	488	244	244	976	.	1220	488	1707	.	.	.	5611
1.00 - 1.49	.	.	488	732	.	732	732	244	.	.	244	.	3172
1.50 - 1.99	.	.	244	.	.	.	.	.	.	.	.	.	244
2.00 - 2.49	.	.	.	.	244	.	.	.	.	.	.	.	244
2.50 - 2.99	.	.	.	.	.	244	.	.	.	.	.	.	244
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	488	488	976	976	1220	1220	1952	732	1707	0	244	0	

(Sheet 4 of 4)

Table B3

Annual Joint Distribution of H_{mo} versus T_p (All Years)

Annual 1980-1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec)												Total
	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	
0.00 - 0.49	27	14	26	60	86	114	332	278	189	66	126	5	1323
0.50 - 0.99	37	136	255	509	592	526	882	744	801	140	229	16	4867
1.00 - 1.49	.	9	143	405	424	251	284	212	322	40	121	3	2214
1.50 - 1.99	.	.	13	164	245	111	83	78	126	32	72	4	928
2.00 - 2.49	.	.	1	24	95	67	54	37	59	27	36	1	401
2.50 - 2.99	.	.	.	1	12	32	18	13	32	10	24	1	143
3.00 - 3.49	.	.	.	.	1	12	12	12	14	5	8	1	65
3.50 - 3.99	.	.	.	.	.	1	6	7	11	4	5	.	34
4.00 - 4.49	.	.	.	.	.	.	2	4	7	1	3	1	18
4.50 - 4.99	.	.	.	.	.	.	.	1	2	.	.	1	4
5.00 - Greater	.	.	.	.	.	.	1	.	1	1	1	1	5
Total	64	159	438	1163	1455	1114	1674	1386	1564	326	625	34	

Table B4

Monthly Joint Distribution of H_{mo} versus T_p (All Years)

January 1980-1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	88	8	8	80	72	40	151	247	215	48	96	.	1053
0.50 - 0.99	72	207	231	406	406	351	351	709	829	104	223	.	3889
1.00 - 1.49	.	16	159	598	534	247	207	199	486	24	56	8	2534
1.50 - 1.99	.	.	32	335	414	183	96	104	231	24	48	.	1467
2.00 - 2.49	.	.	.	32	175	183	96	32	104	32	24	8	686
2.50 - 2.99	.	.	.	.	16	64	64	16	64	16	40	.	280
3.00 - 3.49	.	.	.	.	.	16	24	8	32	.	.	.	80
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	8	.	.	.	8
4.50 - 4.99	.	.	.	.	.	.	.	.	8	.	.	.	8
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	160	231	430	1451	1617	1084	989	1315	1977	248	487	16	

February 1980-1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	9	.	9	44	61	44	87	79	79	26	105	.	543
0.50 - 0.99	52	96	175	419	471	314	497	689	1003	17	166	9	3908
1.00 - 1.49	.	9	131	646	620	253	305	332	532	70	201	.	3099
1.50 - 1.99	.	.	9	227	358	183	113	113	192	52	96	.	1343
2.00 - 2.49	.	.	.	79	166	44	35	79	79	44	96	.	622
2.50 - 2.99	.	.	.	9	17	52	17	9	96	17	61	9	287
3.00 - 3.49	.	.	.	.	.	17	9	26	26	17	17	.	112
3.50 - 3.99	.	.	.	.	.	.	.	9	9	.	9	.	27
4.00 - 4.49	.	.	.	.	.	.	.	9	35	.	9	.	53
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	9	.	.	.	.	.	9
Total	61	105	324	1424	1693	907	1072	1345	2051	243	760	18	

March 1980-1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	7	.	7	15	37	37	103	29	125	66	118	.	544
0.50 - 0.99	7	74	169	434	420	398	611	700	898	118	221	.	4050
1.00 - 1.49	.	7	214	434	486	331	368	287	663	52	309	.	3151
1.50 - 1.99	.	.	7	243	265	110	103	155	243	66	103	.	1295
2.00 - 2.49	.	.	.	22	66	44	103	52	133	29	88	.	537
2.50 - 2.99	.	.	.	.	22	15	22	7	44	15	37	.	162
3.00 - 3.49	.	.	.	.	7	15	7	15	44	7	7	.	102
3.50 - 3.99	.	.	.	.	.	.	.	15	52	.	15	.	82
4.00 - 4.49	.	.	.	.	.	.	7	15	15	.	22	.	59
4.50 - 4.99	.	.	.	.	.	.	.	.	15	.	.	.	15
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	14	81	397	1148	1303	950	1324	1275	2232	353	920	0	

(Continued)

(Sheet 1 of 4)

Table B4 (Continued)

April 1980-1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	8	8	15	45	30	23	264	203	151	75	75	.	897
0.50 - 0.99	68	173	249	430	618	497	859	844	1070	219	377	.	5404
1.00 - 1.49	.	8	106	226	407	309	369	324	294	53	143	.	2239
1.50 - 1.99	.	.	.	158	158	90	106	106	166	23	83	.	890
2.00 - 2.49	.	.	.	38	60	8	45	60	45	23	8	.	287
2.50 - 2.99	.	.	.	.	8	23	30	15	30	23	15	.	144
3.00 - 3.49	.	.	.	.	.	30	15	23	23	.	.	.	91
3.50 - 3.99	.	.	.	.	.	8	30	.	.	.	.	.	38
4.00 - 4.49	.	.	.	.	.	.	8	.	.	.	.	.	8
4.50 - 4.99	.	.	.	.	.	.	.	8	.	.	.	.	8
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	76	189	370	897	1281	988	1726	1583	1779	416	701	0	

May 1980-1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	7	22	52	96	148	141	392	266	215	52	133	.	1524
0.50 - 0.99	22	192	377	637	585	888	1214	888	681	104	215	.	5803
1.00 - 1.49	.	7	133	244	333	207	370	215	266	15	74	.	1864
1.50 - 1.99	.	.	7	59	74	44	104	59	89	22	59	.	517
2.00 - 2.49	.	.	.	15	44	52	7	30	7	22	22	.	199
2.50 - 2.99	.	.	.	.	22	7	7	7	7	15	7	.	72
3.00 - 3.49	.	.	.	.	.	.	.	.	.	7	7	.	14
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	29	221	569	1051	1206	1339	2094	1465	1265	237	517	0	

June 1980-1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	24	32	48	129	201	346	707	547	209	40	32	.	2315
0.50 - 0.99	48	217	354	651	723	683	1672	989	523	129	48	.	6037
1.00 - 1.49	.	8	88	225	177	177	201	105	96	.	40	.	1117
1.50 - 1.99	.	.	16	56	105	56	32	16	96	.	48	.	425
2.00 - 2.49	.	.	.	.	24	16	48	8	.	.	.	.	96
2.50 - 2.99	.	.	.	.	.	8	.	.	.	.	.	.	8
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	72	257	506	1061	1230	1286	2660	1665	924	169	168	0	

(Continued)

(Sheet 2 of 4)

Table B4 (Continued)

July 1980-1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	8	16	47	86	203	320	1008	680	266	94	195	16	2939
0.50 - 0.99	31	148	336	703	906	805	1469	898	406	211	125	63	6101
1.00 - 1.49	.	16	63	195	227	86	125	39	39	.	.	.	790
1.50 - 1.99	.	.	.	47	8	16	23	16	39	.	.	.	149
2.00 - 2.49	.	.	.	8	.	.	8	.	.	.	.	.	16
2.50 - 2.99	.	.	.	.	.	.	.	.	.	.	.	.	0
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	39	180	446	1039	1344	1227	2633	1633	750	305	320	79	

August 1980-1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	23	23	54	107	146	192	583	507	353	77	100	.	2165
0.50 - 0.99	38	92	230	553	844	698	1266	867	821	153	315	38	5915
1.00 - 1.49	.	8	130	307	261	184	223	123	84	15	31	.	1366
1.50 - 1.99	.	.	.	69	138	54	31	15	15	.	31	.	353
2.00 - 2.49	.	.	.	15	31	15	15	.	31	8	8	.	123
2.50 - 2.99	.	.	.	.	8	.	15	.	8	.	8	.	39
3.00 - 3.49	.	.	.	.	8	8	8	.	8	.	.	.	32
3.50 - 3.99	.	.	.	.	.	.	.	8	.	.	.	.	8
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	61	123	414	1051	1436	1151	2141	1520	1320	253	493	38	

September 1980-1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	8	8	8	31	23	15	107	244	214	92	84	8	842
0.50 - 0.99	.	107	176	405	534	588	893	779	1000	145	282	.	4909
1.00 - 1.49	.	8	84	466	466	313	496	237	328	92	160	8	2658
1.50 - 1.99	.	.	8	137	282	145	92	115	61	23	107	8	978
2.00 - 2.49	.	.	.	31	92	53	76	23	61	61	61	.	458
2.50 - 2.99	.	.	.	.	.	46	23	8	.	8	8	.	93
3.00 - 3.49	.	.	.	.	.	8	.	8	8	8	8	.	40
3.50 - 3.99	.	.	.	.	.	.	.	.	8	8	8	.	24
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	.	8	.	.	8
Total	8	123	276	1070	1397	1168	1687	1414	1680	445	718	24	

(Continued)

(Sheet 3 of 4)

Table B4 (Concluded)

October 1980-1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	29	.	.	.	44	73	169	125	198	29	118	.	785
0.50 - 0.99	29	59	169	353	382	316	683	507	926	176	353	7	3960
1.00 - 1.49	.	.	169	588	360	198	220	287	411	81	191	.	2505
1.50 - 1.99	.	.	29	235	375	125	88	103	169	103	206	29	1462
2.00 - 2.49	.	.	.	22	118	162	66	81	140	44	66	7	706
2.50 - 2.99	.	.	.	.	37	96	29	59	44	22	66	.	353
3.00 - 3.49	.	.	.	.	.	29	7	7	15	15	37	7	117
3.50 - 3.99	.	.	.	.	.	.	7	22	.	22	7	.	58
4.00 - 4.49	.	.	.	.	.	.	7	7	15	.	.	7	36
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	7	7
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	7	7
Total	58	59	367	1198	1316	999	1276	1198	1918	492	1044	71	

November 1980-1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	43	35	26	26	43	104	277	190	95	61	199	26	1125
0.50 - 0.99	43	87	364	641	571	476	511	537	606	121	121	43	4121
1.00 - 1.49	.	17	260	511	684	398	277	251	268	43	104	26	2839
1.50 - 1.99	.	.	17	208	329	199	121	69	104	52	9	9	1117
2.00 - 2.49	.	.	.	26	121	121	113	35	26	17	9	.	468
2.50 - 2.99	.	.	.	.	9	35	9	17	43	.	17	.	130
3.00 - 3.49	.	.	.	.	.	9	17	43	.	9	9	.	87
3.50 - 3.99	.	.	.	.	.	.	9	9	35	17	9	.	79
4.00 - 4.49	.	.	.	.	.	.	.	9	9	9	.	.	27
4.50 - 4.99	.	.	.	.	.	.	.	9	.	.	.	.	9
5.00 - Greater	.	.	.	.	.	.	.	.	.	.	.	.	0
Total	86	139	667	1412	1757	1342	1334	1169	1186	329	477	104	

December 1980-1991, Gage 630
Percent Occurrence(X100) of Height and Period

Height(m)	Period(sec) 2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-Longer	Total
0.00 - 0.49	81	27	45	63	18	27	108	217	126	135	280	9	1136
0.50 - 0.99	36	181	244	487	650	235	442	469	830	171	271	36	4052
1.00 - 1.49	.	.	199	469	605	325	226	135	406	36	135	.	2536
1.50 - 1.99	.	.	27	217	487	144	90	63	99	9	63	.	1199
2.00 - 2.49	.	.	18	.	280	117	36	45	72	45	54	.	667
2.50 - 2.99	.	.	.	.	.	45	.	18	54	.	27	.	144
3.00 - 3.49	.	.	.	.	.	9	63	18	18	.	9	.	117
3.50 - 3.99	.	.	.	.	.	.	27	18	27	.	9	.	81
4.00 - 4.49	.	.	.	.	.	.	.	9	9	9	9	.	36
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - Greater	.	.	.	.	.	.	.	.	9	9	9	.	27
Total	117	208	533	1236	2040	902	992	992	1650	414	866	45	

(Sheet 4 of 4)

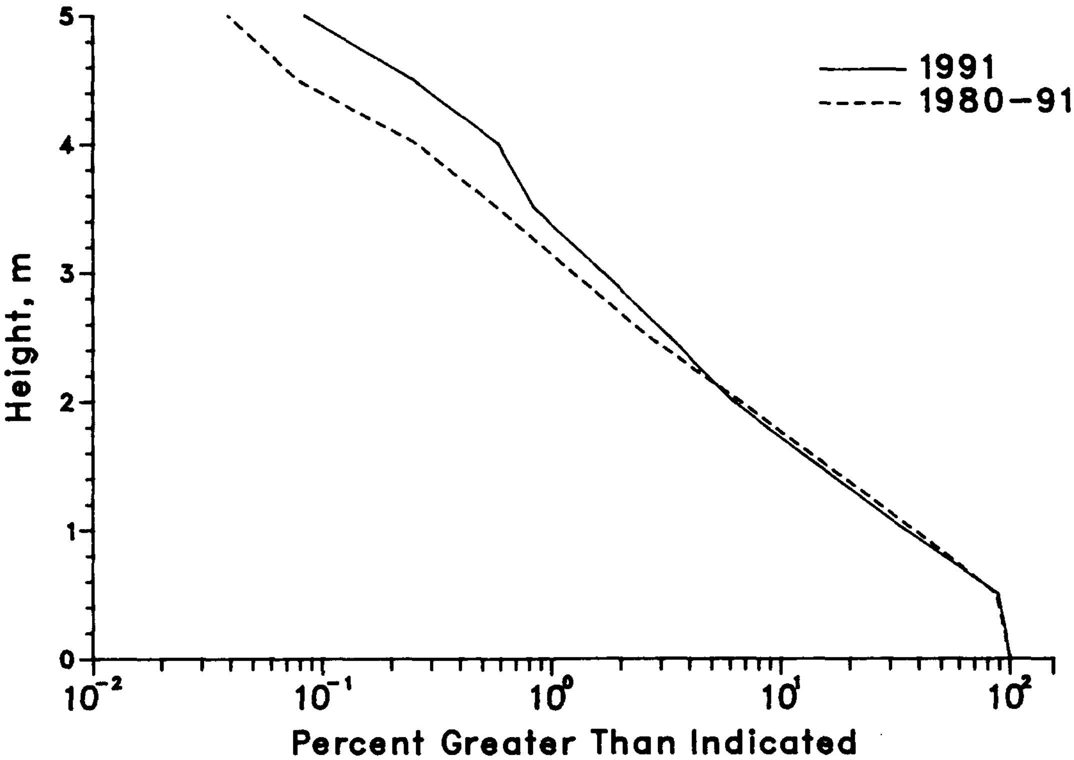


Figure B2. Annual cumulative wave height distributions for Gage 630

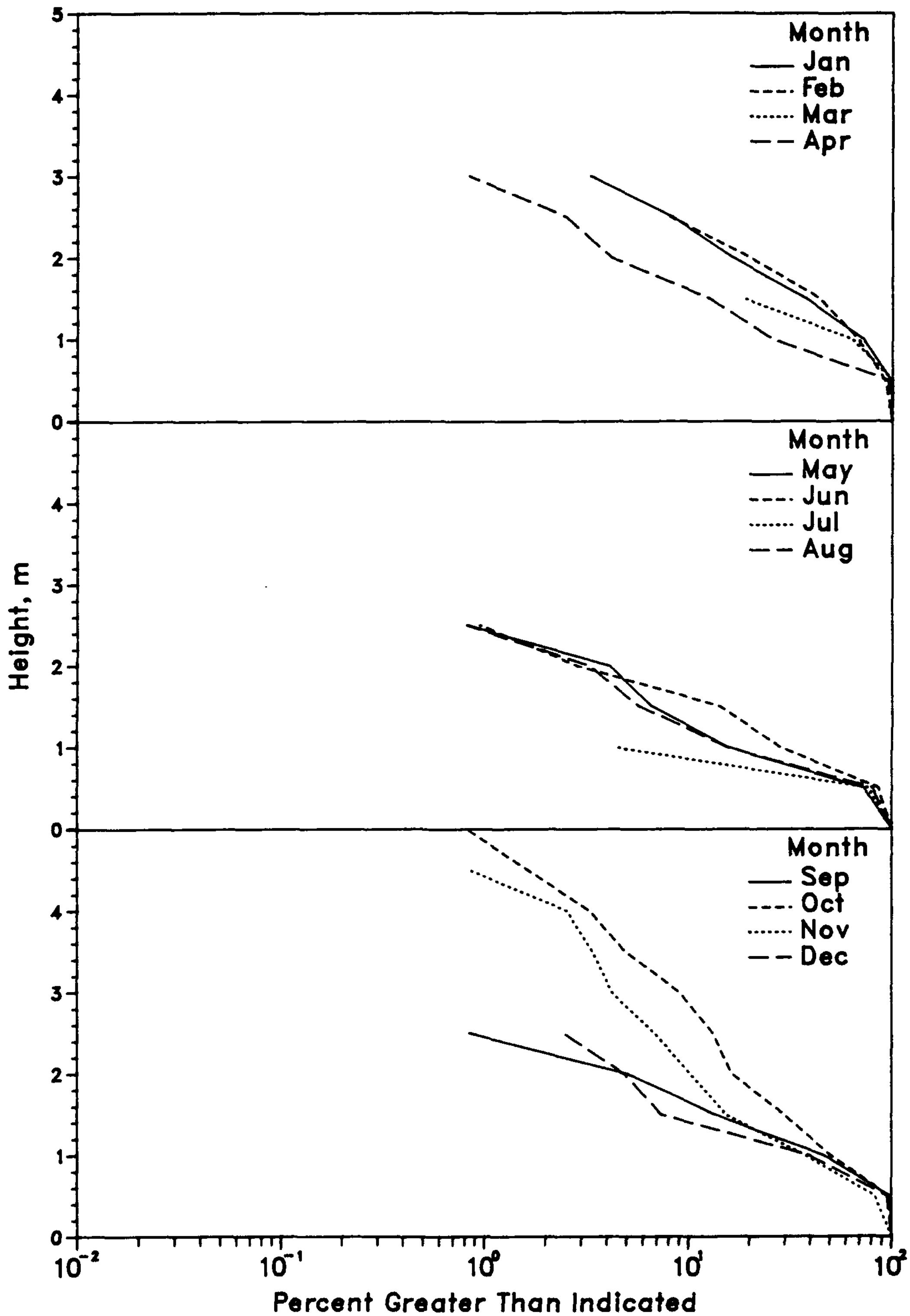


Figure B3. 1991 monthly wave height distributions for Gage 630

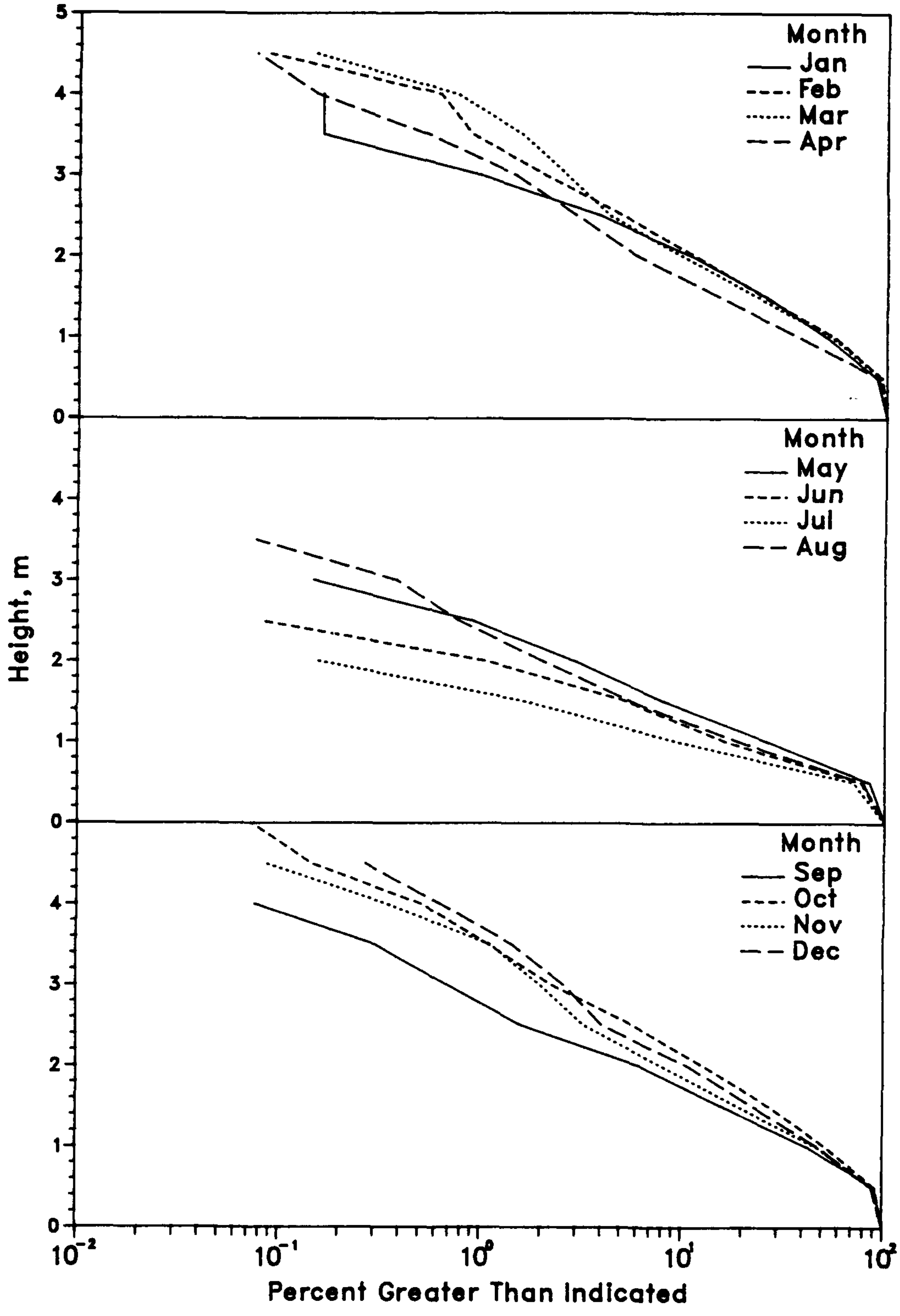


Figure B4. 1980-1991 monthly wave height distributions for Gage 630

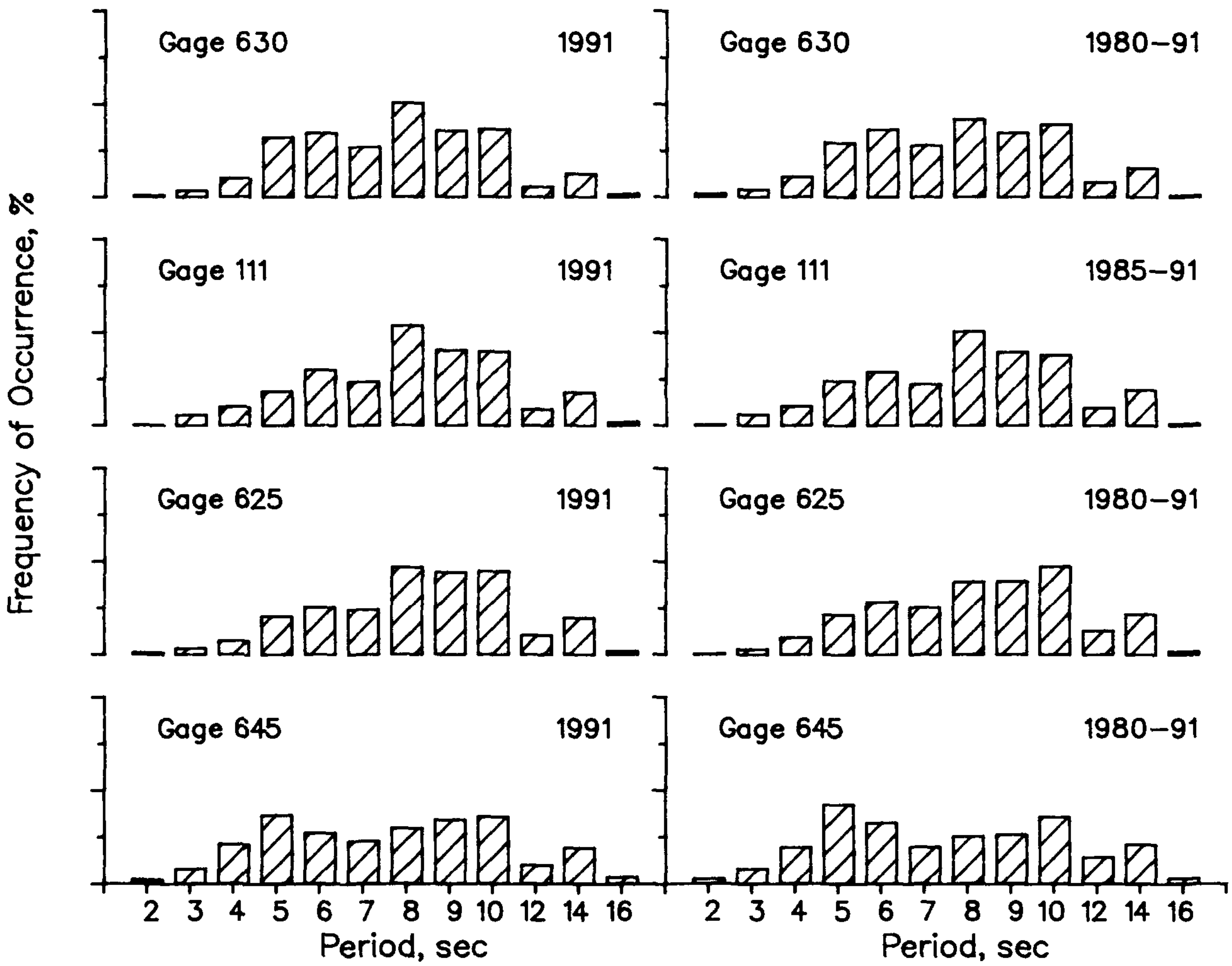


Figure B5. Annual wave period distributions for all gages

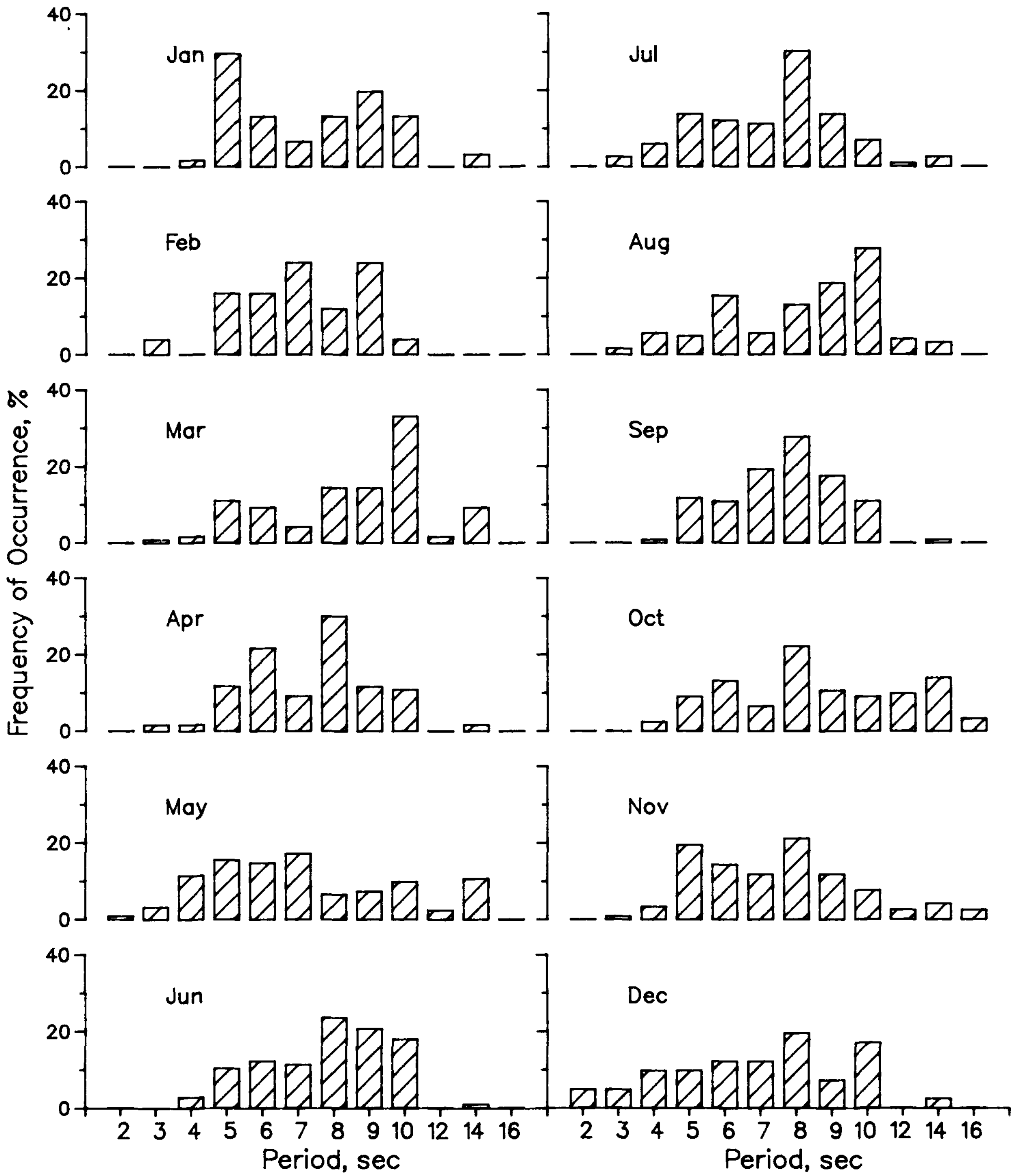


Figure B6. 1991 monthly wave period distributions for Gage 630

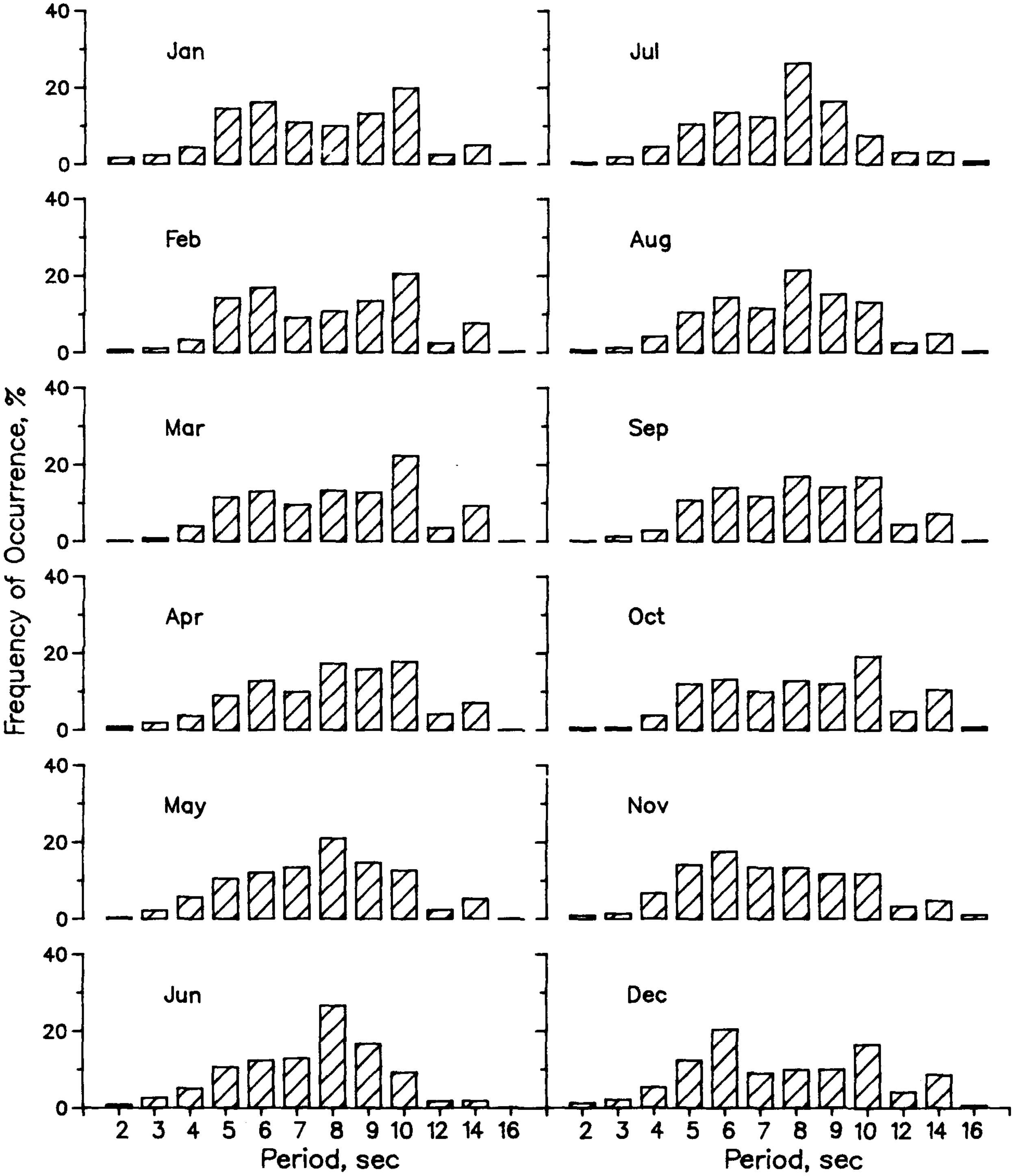


Figure B7. 1980-1991 monthly wave period distributions for Gage 630

Table B5

1991 Persistence of H_{mo} for Gage 630

Height	Consecutive Day(s) or Longer																		
(m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19+
0.5		14	13			15		12		10	9	8	6					5	4
1.0	52	37	28	20	13	8	4	3	2				1						
1.5	42	25	12	5		2	1												
2.0	22	10	3		2	1													
2.5	12	5	3		1														
3.0	5		3	1															
3.5	3	2																	
4.0	3	2																	

Table B6

1980 through 1991 Average Persistence of H_{mo} for Gage 630

Height	Consecutive Day(s) or Longer																		
(m)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19+
0.5	20	18	16	15		14	12		11	10		9	8	7	6	5			4
1.0	51	34	25	17	14	10	7	5	4	3		2					1		
1.5	39	22	11	6	4	2			1										
2.0	22	11	4	2		1													
2.5	11	5	2																
3.0	5	2	1																
3.5	3	1																	
4.0	2	1																	

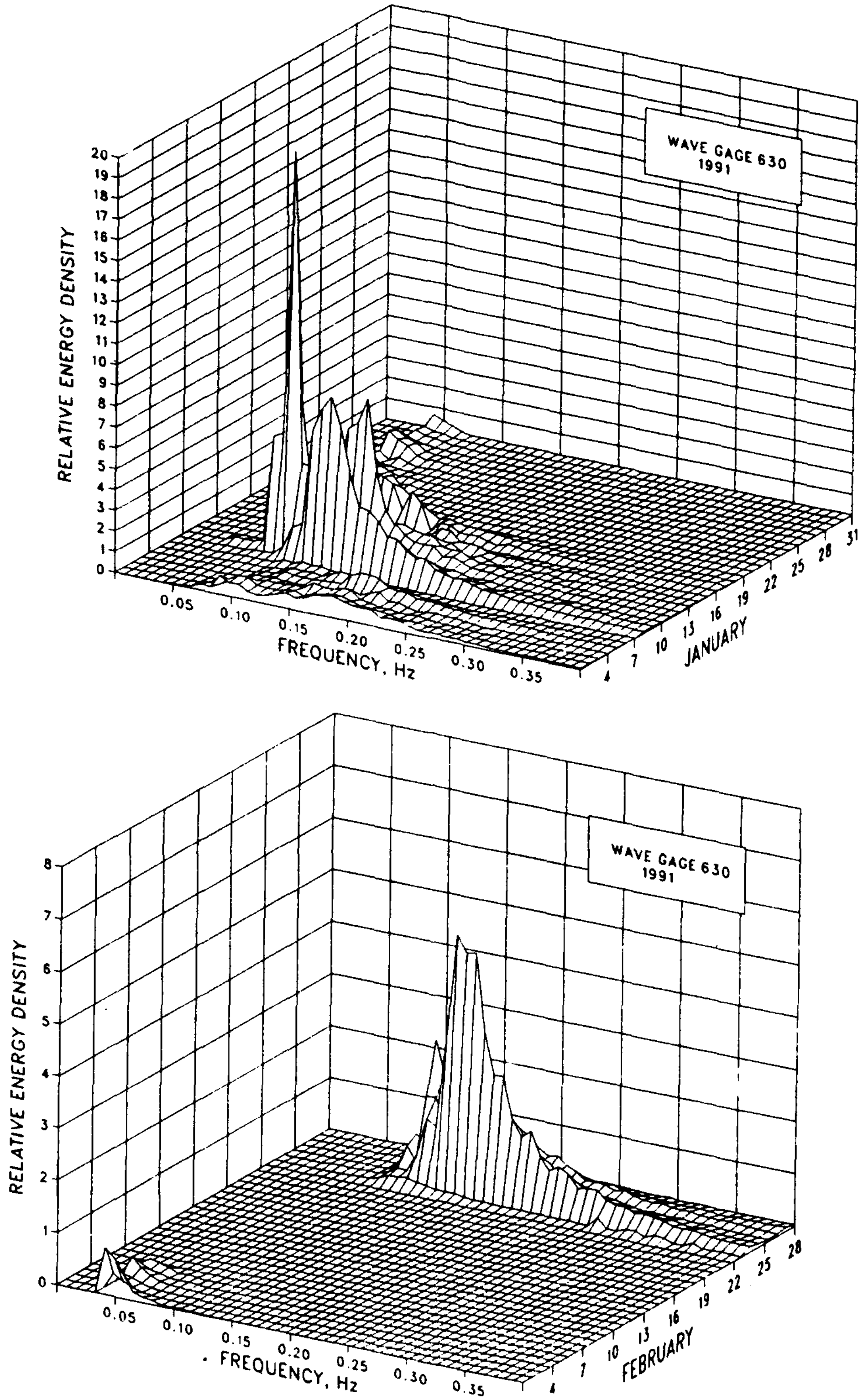
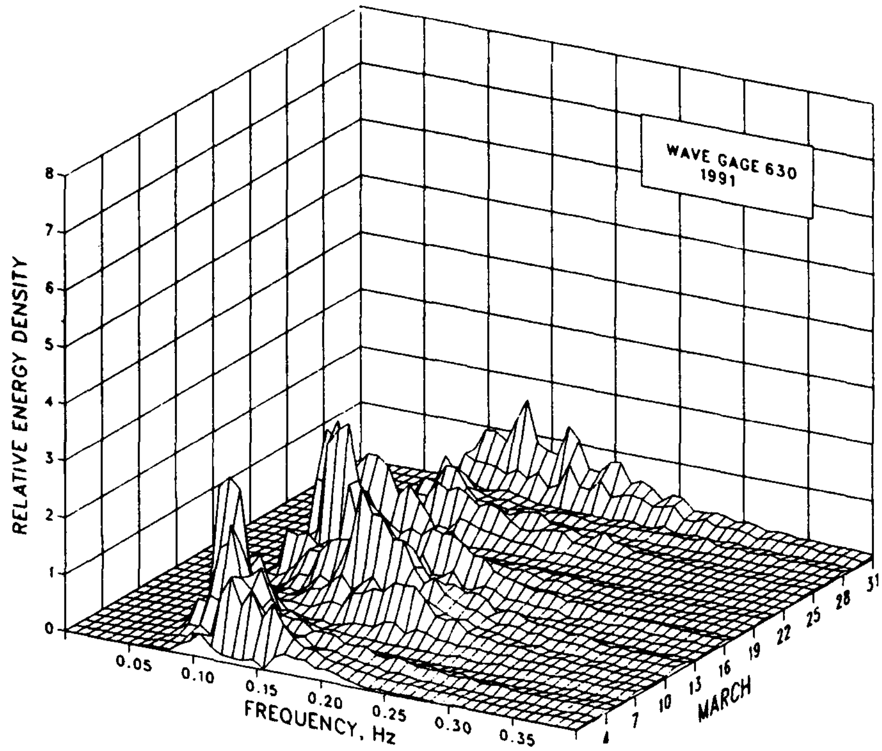
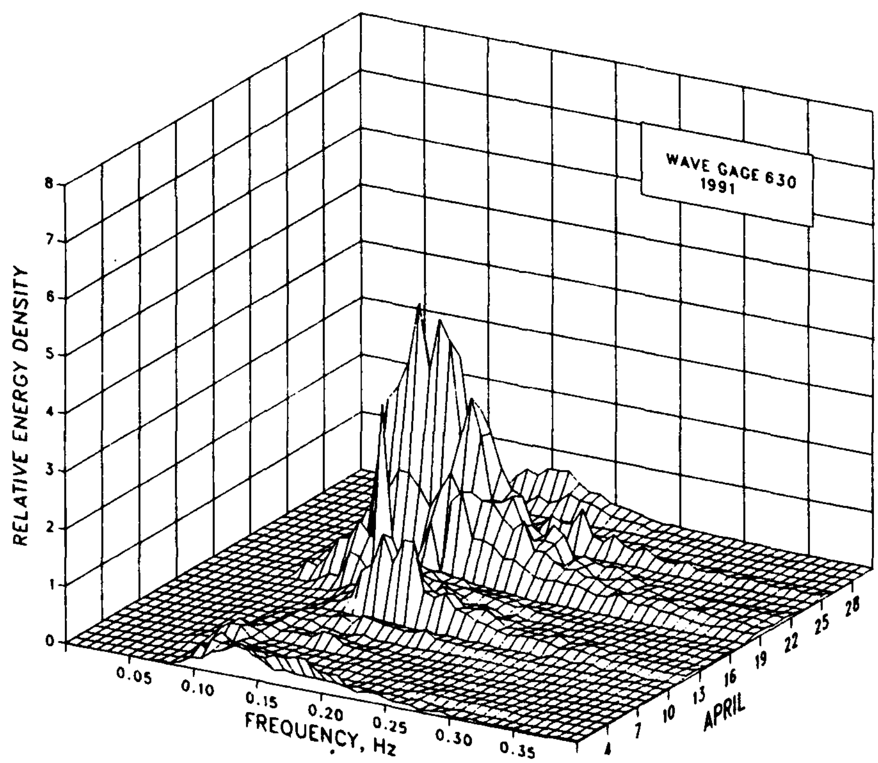


Figure B8. 1991 monthly spectra for Gage 630 (Sheet 1 of 6)





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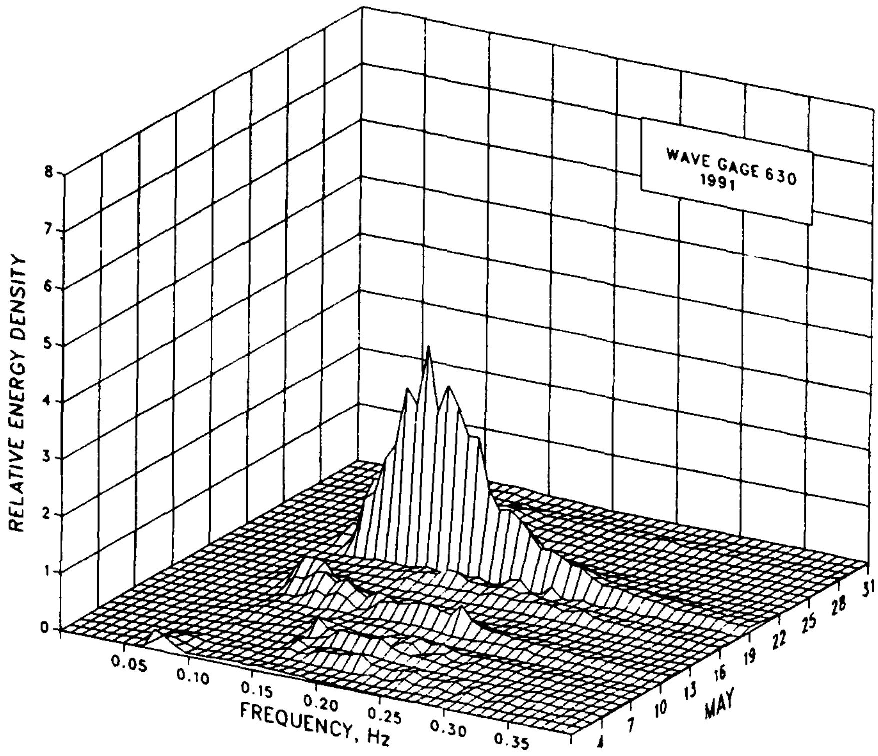

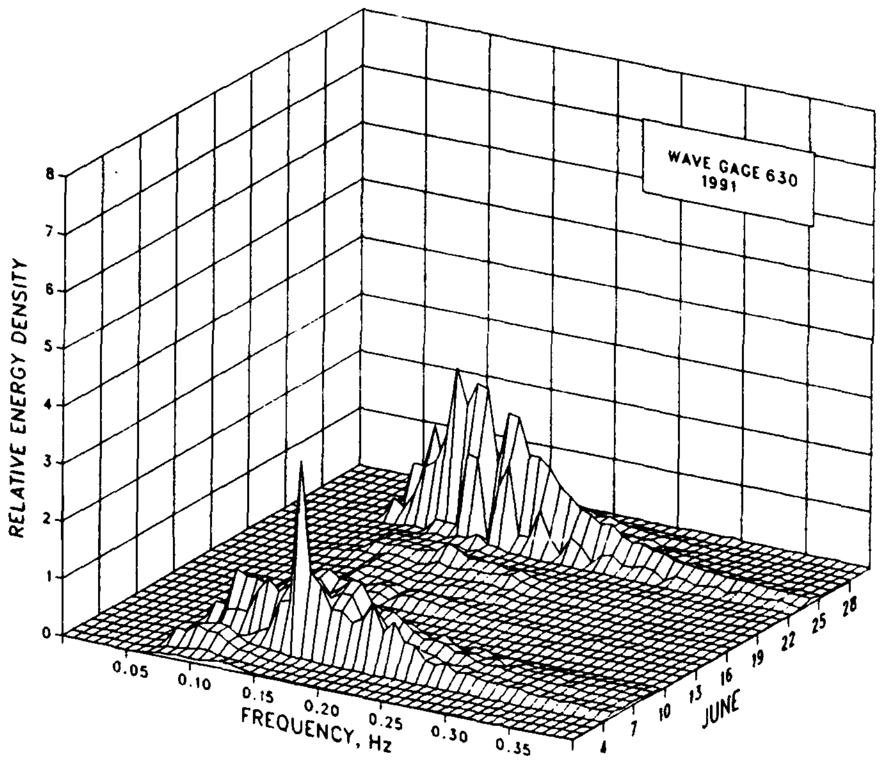

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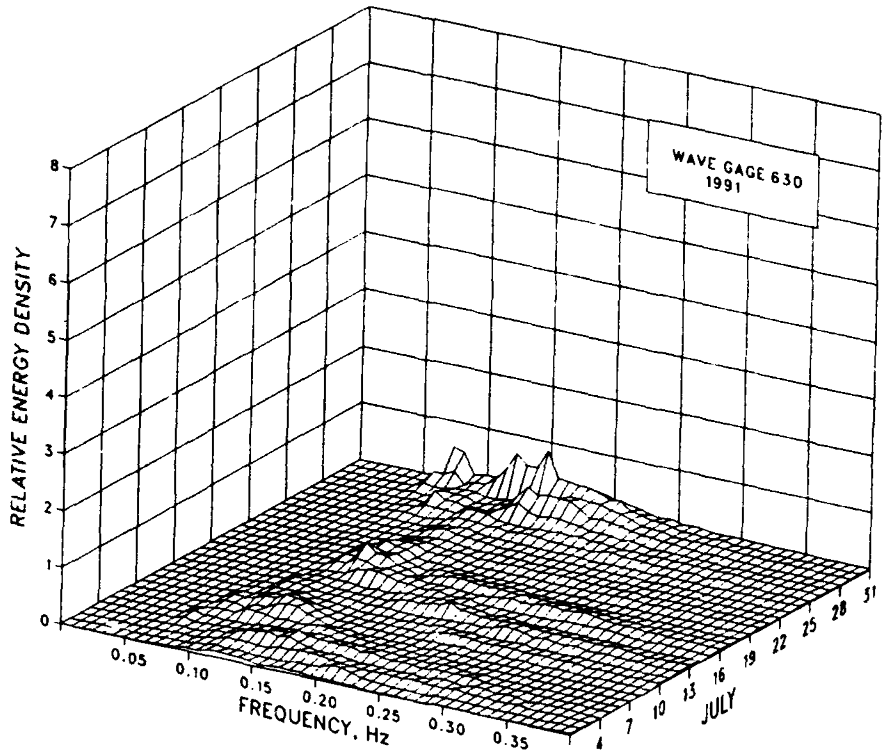

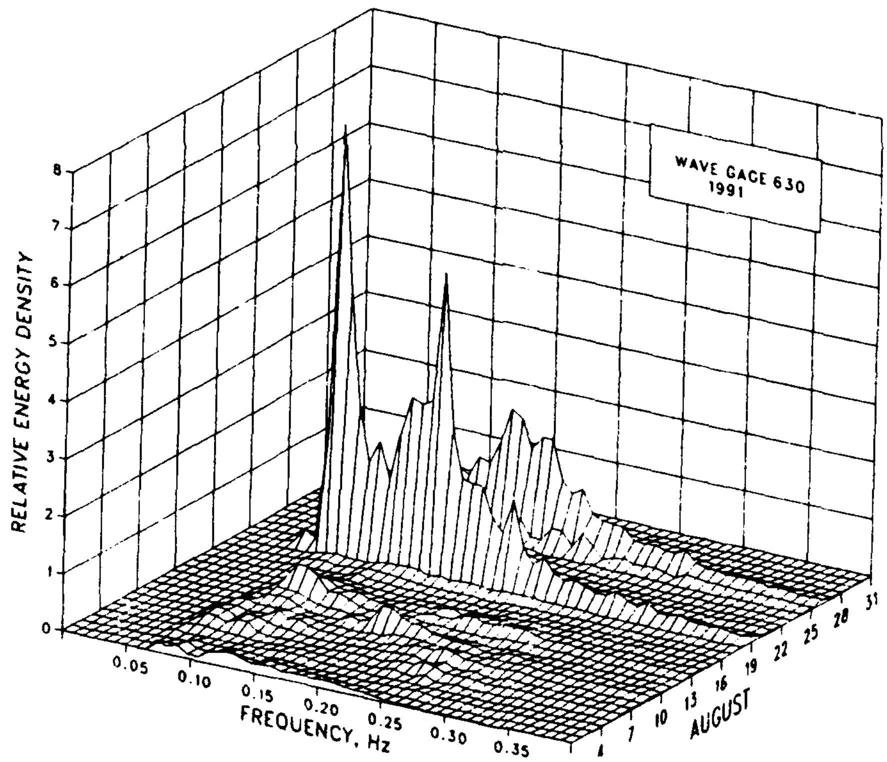

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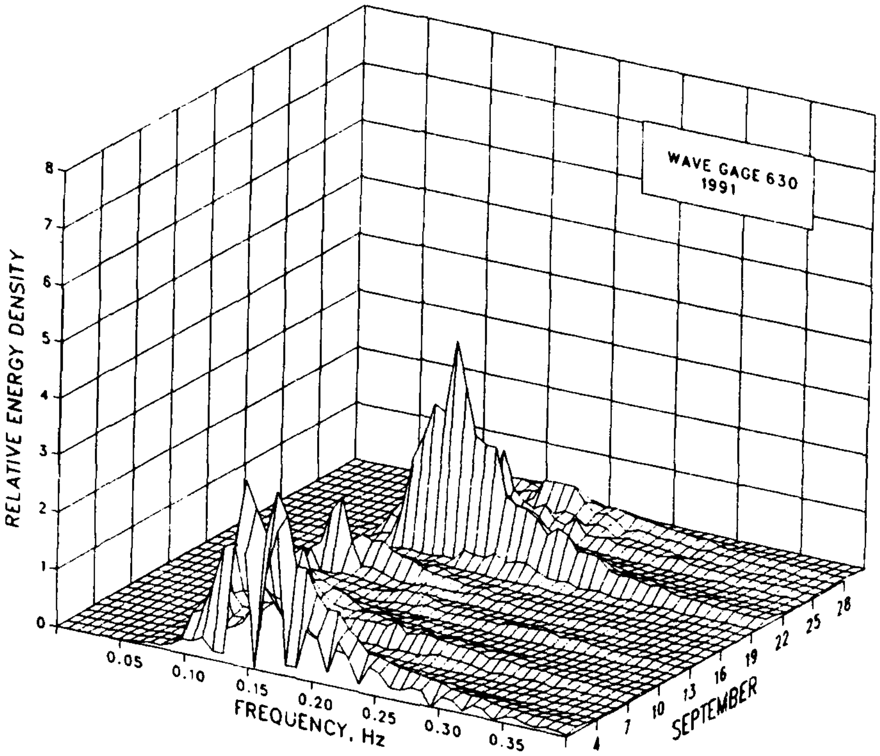

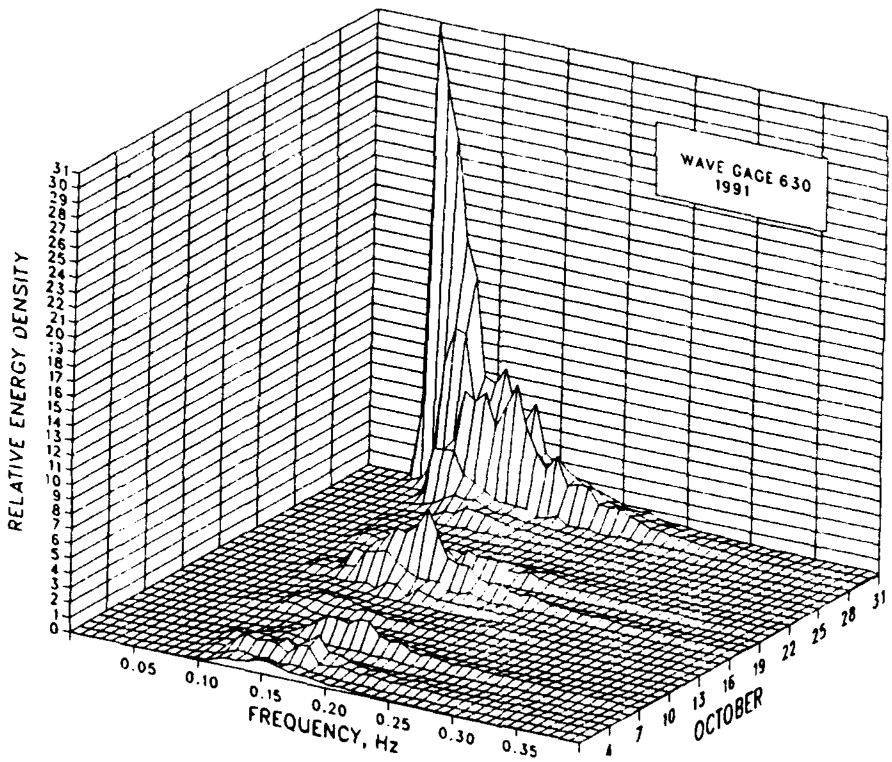

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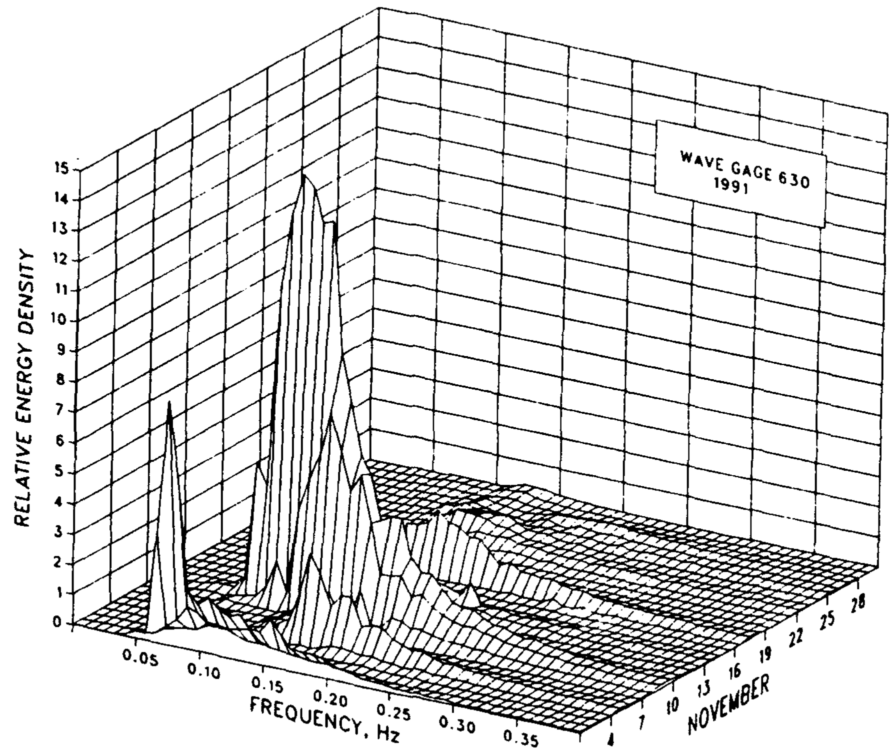

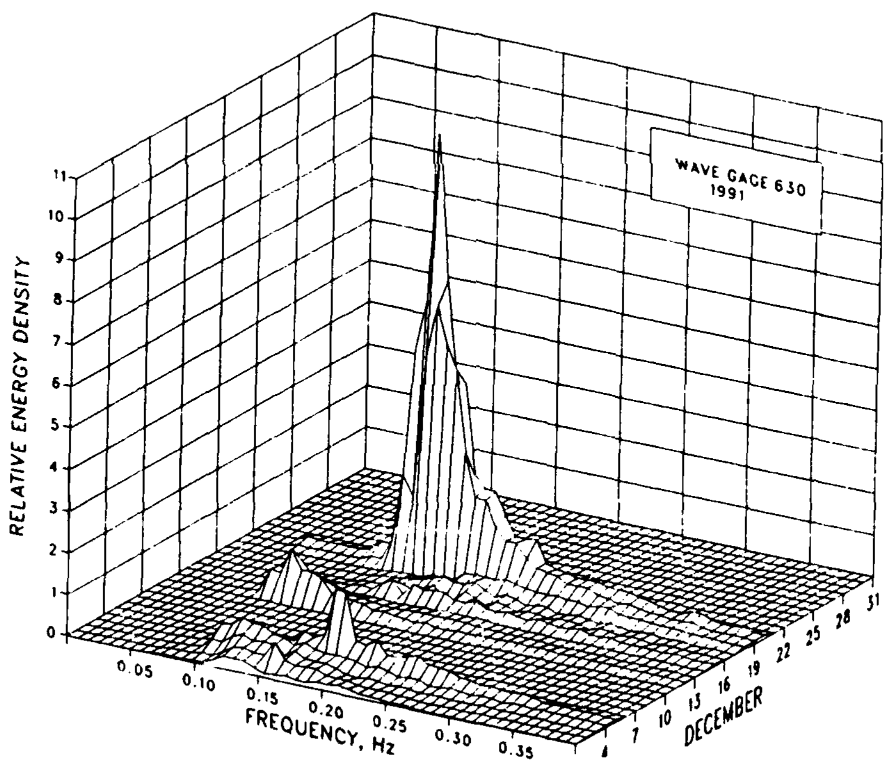

Figure B8. (Sheet 6 of 6)

Table B7

Wave Statistics for Gage 630

	1991							1980-1991						
	Height				Period			Height				Period		
Month	Mean m	Std. Dev. m	Extreme m	Date	Mean sec	Std. Dev. sec	Number Obs.	Mean m	Std. Dev. m	Extreme m	Date	Mean sec	Std. Dev. sec	Number Obs.
Jan	1.5	0.7	3.2	9	8.0	2.5	61	1.2	0.7	4.5	1983	8.1	2.7	1255
Feb	1.4	0.7	2.8	23	7.5	1.7	25	1.2	0.7	5.1	1987	8.4	2.6	1146
Mar	1.2	0.5	2.1	30	9.2	2.4	118	1.2	0.7	4.7	1983	8.7	2.6	1358
Apr	1.0	0.6	3.5	20	7.9	1.8	120	1.0	0.6	5.0	1988	8.6	2.6	1327
May	0.8	0.5	2.6	19	7.8	2.9	122	0.9	0.5	3.3	1986	8.1	2.5	1351
Jun	0.9	0.5	2.7	23	8.4	1.9	106	0.8	0.4	2.7	1991	7.8	2.2	1244
Jul	0.7	0.2	1.3	30	7.8	2.1	116	0.7	0.3	2.1	1985	8.1	2.4	1280
Aug	0.8	0.5	3.5	19	8.9	2.5	123	0.8	0.5	3.6	1981	8.2	2.5	1303
Sep	1.1	0.5	2.6	1	8.1	1.7	119	1.1	0.6	6.1	1985	8.6	2.6	1310
Oct	1.4	1.0	5.4	31	9.7	3.4	122	1.3	0.7	5.4	1991	8.8	2.8	1361
Nov	1.1	0.9	4.6	9	8.2	2.9	118	1.1	0.7	4.6	1991	7.9	2.8	1155
Dec	1.0	0.5	2.9	19	7.5	2.6	41	1.2	0.8	5.6	1980	8.2	2.9	1108
Annual	1.1	0.6	5.4	Oct	8.3	2.6	1191	1.0	0.6	6.1	Sep 1985	8.3	2.6	15198

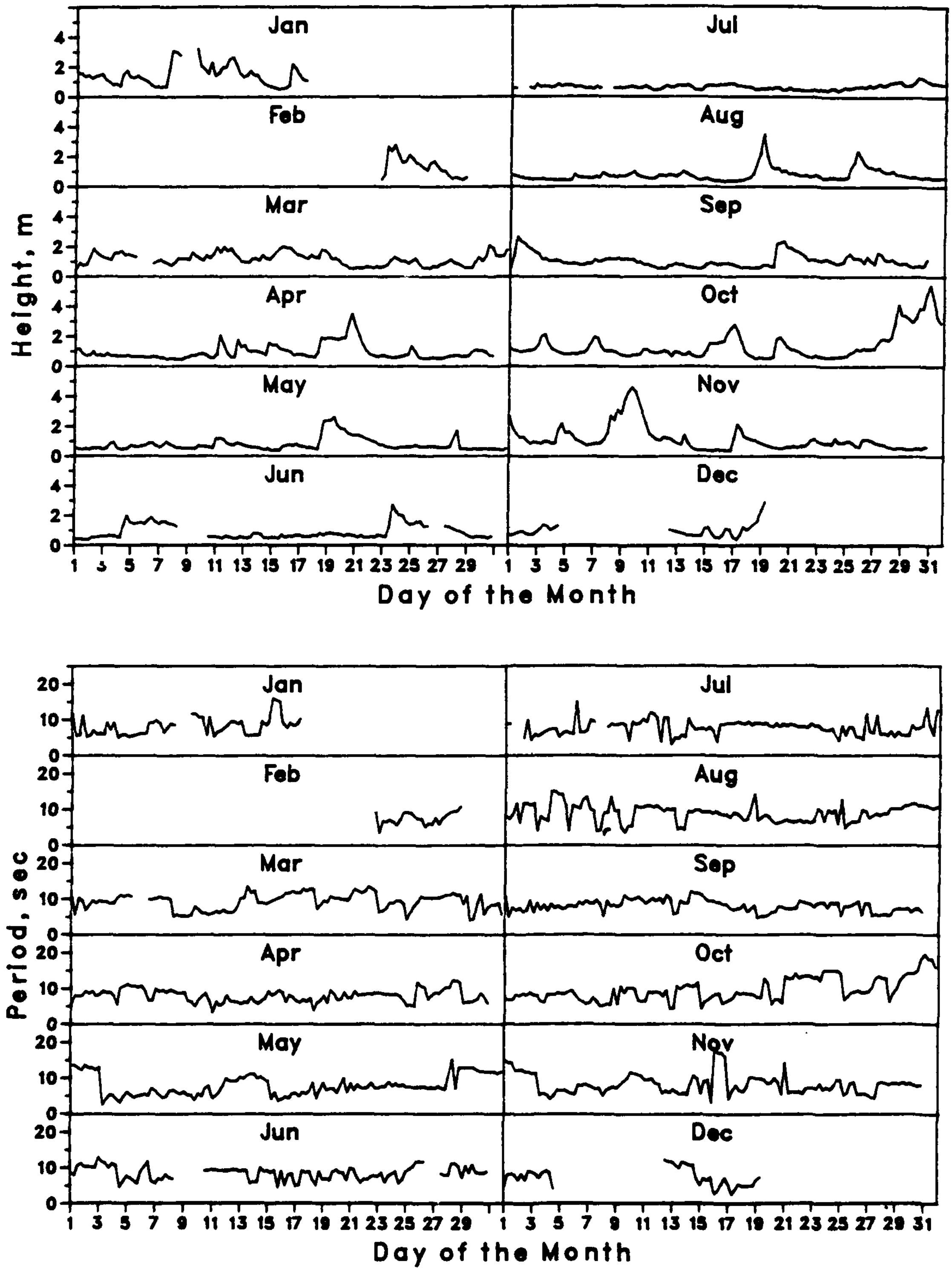

Figure B9. Time histories of wave height and period for Gage 630

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13. ABSTRACT *(Maximum 200 words)*

This report provides basic data and summaries for the measurements made during 1991 at the US Army Engineer Waterways Experiment Station (WES) Coastal Engineering Research Center's (CERC's) Field Research Facility (FRF) in Duck, NC. The report includes comparisons of the present year's data with cumulative statistics from 1980 to the present.

Meteorological and oceanographic data, monthly bathymetric survey results, samples of biannual aerial photography, and descriptions of 18 storms that occurred during the year are summarized in this report. The year was highlighted by a major storm (the "Halloween Storm") in late October. Waves with 6-m significant height and periods exceeding 21 sec were measured 6 km from shore.

This report is the 13th in a series of annual summaries of data collected at the FRF that began with Miscellaneous Report CERC-82-16, which summarized data collected during 1977-1979. These reports are available from the WES Technical Report Distribution Section of the Information Technology Laboratory, Vicksburg, MS.

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14. (Continued).

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